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Geotechnical Engineering Report: Wall 9.05R-A

WSDOT I-405 Renton to Bellevue Design-Build

Renton to Bellevue, Washington

Project # PS19-20316-0

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January 11, 2022

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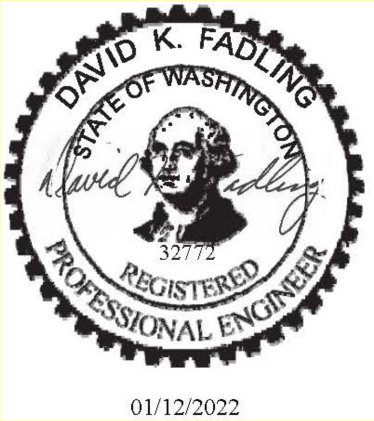

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List of acronyms

ESU	Engineering Stratigraphic Unit
FS	factor of safety
GLE	General Limit Equilibrium
I-405	Interstate 405
NW11	Noise Wall 11
Project GDM	Project Geotechnical Design Manual, consisting of WSDOT's 2015 *Geotechnical Design Manual*, along with project-specific Chapters 6 (Seismic) and 15 (Retaining Walls) from Request for Proposal Addendum
Sta.	Station
Wood	Wood Environment & Infrastructure Solutions, Inc.
WSDOT	Washington State Department of Transportation

1.0 Description of Structure

This document presents our geotechnical engineering analysis for wall 9.05R-A, in support of the Washington State Department of Transportation (WSDOT) Interstate 405 (I-405) Renton to Bellevue Design-Build project. This report has been prepared in accordance with the requirements presented in the I-405 Renton to Bellevue Widening Project Request for Proposal, specifically Section 2.6.5.3, and the applicable sections of the WSDOT *Geotechnical Design Manual* M 46-03.11 (WSDOT 2015). The Project Geotechnical Design Manual (GDM) consists of WSDOT's 2015 *Geotechnical Design Manual*, along with project-specific Chapters 6 (Seismic) and 15 (Retaining Walls) from the Request for Proposal Addendum 9.

The retaining wall structure will consist of soldier piles, lagging and tie-back anchors where required. The height will vary from 0 feet of exposed face at the south and north ends to about 15 feet of exposed face at the central portion of the wall. A cut slope into existing soils will extend below the bottom of the wall to the highway. Wall 9.05R-A will also support a portion of Noise Wall 11 (NW11). This portion of the noise wall will be structurally founded on the soldier piles by means of a grade beam. Geotechnical engineering analyses for the remaining sections of NW11 beyond retaining wall 9.05R-A are addressed in a separate report.

This report has been revised to include updated design loading and lateral earth pressure diagrams.

The wall design will provide future compatibility for roadway widening by excavating the slope between the wall and the road. The geotechnical engineering detailed in this report focuses on the current retaining wall while considering future compatibility as needed. Details are discussed in Section 6.0.

1.1 Structure Location

Wall 9.05R-A is located within Segment 2A of the project. The wall is approximately 240 feet long. The approximate location of the wall and subsurface explorations are shown on the retaining wall plan and profile and cross section (Figures A-1 and A-3 in Appendix A). Table 1 presents a summary of the design section considered for this wall.

Table 1: Summary of Wall Design Section

Boreholes	Cut/Fill	Design Station	Current/Future Retained Height (feet)	Foreslope at Current Wall Height (deg)	Average Backslope (deg)	Wall Type
W-60-20 W-62-20	Cut	2+60	18.0/30.0	27	12	Soldier Pile

Abbreviations:
deg = degrees
Sta. = Station

As mentioned earlier, wall 9.05R-A will be a combination of cantilever soldier piles at the south and north ends of the wall, and soldier piles with tieback anchors along the central section.

Temporary timber lagging and permanent concrete facing, as shown on WSDOT Bridge Standard Drawing 8.1-A3-2, is anticipated behind the final facing structure.

The section at Station (Sta). 2+60 was used for the geotechnical engineering of wall 9.05R-A, as it is located near the tallest wall section. The retained height is about 18.0 feet; the top of the wall will be near elevation 163 feet, and the top of the cut slope in front of the wall is near elevation 145 feet. Elevations referenced in this report are approximate and are based on the North American Vertical Datum of 1988.

The wall was analyzed for global stability in the future wall condition in order to determine the minimum pile embedment and other stability requirements that need to be accounted for during design of the current wall. External factored wall loads imposed at the top of the retaining wall by NW11 bearing on the retaining wall have been provided by the noise wall designers as shown in Table 2.

Table 2: Summary of Factored Design Loads

Load	Load Case	
	Strength	Extreme Event I
Vertical (k/ft)	7.0	5.6
Shear (k/ft)	0.5	2.4
Moment (kips-ft/ft)	8.5	47.0

Abbreviations:
k/ft = kips per 1 foot of wall length
kips-ft/ft = kips-foot per 1 foot of wall length

1.2 Site Surface Conditions

The existing ground surface along the wall 9.05R-A face varies from elevation 164 feet within the central portion to approximately elevation 155 feet at the south end and approximately elevation 149 feet at the north end. The proposed grading shows that the I-405 northbound finished pavement along wall 9.05R-A varies within the approximate elevation range from 132 to 134.

2.0 Exploration and Laboratory Testing

The locations of the explorations for wall 9.05R-A are shown on Figures A-1 and A-3 in Appendix A. The amount, location, and depth of the explorations are in compliance with the Project GDM. This includes geotechnical borings W-60-20 and W-62-20, performed by Wood Environment & Infrastructure Solutions, Inc. (Wood) for wall 9.05R-A. The data from these subsurface investigations and other investigations within Segment 2A were used to develop Engineering Stratigraphic Units (ESUs) for design of walls and embankment structures within Segment 2A. An explanation of field exploration procedures and the boring logs can be found in Appendix B, and details are summarized in Table 3. The results of laboratory testing are found in Appendix C. The ESU soil properties are described in detail in Appendix D.

Table 3: Summary of Geotechnical Explorations

Location ID	Date Completed	State Plane Coordinates (WA SPC North NAD 83; survey feet)		Ground Elevation (feet NAVD 88)	Termination Depth (feet)
		Northing	Easting		
W-60-20	05/13/20	204958.136	1304953.182	156.3	40.6
W-62mw-20	05/14/20	205079.873	1305038.659	155.5	46.5

Abbreviations:
NAD = North American Datum of 1983
NAVD = North American Vertical Datum of 1988
SPC = State Plane Coordinate System
WA = Washington

3.0 Subsurface Conditions

3.1 Regional and Site Geology

The project lies within the southern portion of the Puget Sound Lowland physiographic region. The Puget Sound Lowland has undergone physiographic and depositional changes due to at least five glacial episodes. The last glaciation that occurred in the region was the Vashon Stade of the Fraser Glaciation, which ended approximately 13,500 years ago.

The advance of the Vashon Glacier deepened and widened the north/south trending valleys situated between the Olympic Mountains and the Cascade Range in western Washington. In the Seattle area, the Vashon Stade is represented by four stratigraphic units (from oldest to youngest): Lawton Clay, Esperance Sand, Vashon Till, and Vashon recessional deposits, which make up the Vashon Drifeet (Galster and Laprade 1991).

As the Vashon glacial lobe advanced south and blocked the northern portion of the Puget Sound basin, a lake was formed, and fine-grained sediments were deposited. The glaciolacustrine deposit, known as the Lawton Clay, is reported to be present in the Seattle area as high as 150 feet above mean sea level. A fine-to-medium-grained sand unit was deposited above the Lawton Clay by meltwater streams issuing from the advancing ice sheet as it neared the Seattle area. That sand unit is called the Esperance Sand Member. The Lawton Clay and Esperance Sand are sometimes intermixed and interbedded, and the contact between the two soil types may be gradational. Both deposits were overridden by an estimated 3,000 feet of ice, which consolidated them into hard or dense layers. A mantle of the Vashon Till was deposited on top of the Esperance Sand and Lawton Clay. The Esperance Sand and Lawton Clay deposits were overlain by Vashon Till, also overridden by the ice sheet. These units are mantled by recessional deposits that were formed during the retreat of the ice sheet. Holocene modification of the glacial landscape in the last 11,700 years and recent activities helped sculpt the landform that is today.

The geologic unit descriptions and stratigraphy used by Wood are based on the mapped and structural geology (McKnight 1923, Waldron et al. 1962, Mullineaux 1965, Yount et al. 1993, Johnson et al. 1994, Liberty and Pratt 2008, Troost 2012, and WSDOT 2018a and 2018b) and as described by others (Golder 1993, Shannon & Wilson 2000, and GeoEngineers 2008) in the project vicinity. Wood simplified the geologic units for converting them into ESUs, which were used for foundation design of the structure. These modifications to the geologic units consisted of combining the Quaternary period Pleistocene and Holocene epoch soils.

The geologic units encountered near this wall, along with a brief discussion of their descriptions used for the project geology, are provided in Table 4.

Table 4: Geologic Unit Descriptions

Geologic Unit Name		Abbrev.	Geologic Unit Description	Remarks
Quaternary	Fill	Af	Fill placed by humans, both engineered and uncontrolled fill consisting of various materials, including debris; typically dense or stiff if engineered, but very loose to dense or very soft to stiff if uncontrolled fill.	Likely uncontrolled fill at the location of boreholes, or debris from activity of erosion uphill to the east.
	Advance Outwash	Qva	Glaciofluvial sediments deposited as the glacial ice advanced through the Puget Lowland and overridden by the weight of glacial ice; typically stratified, light brown to gray, sand, gravelly sand, and sandy gravel; dense to very dense.	Likely the prevalent soils within the depth of exploration at this site.

3.2 Site Soil Conditions

Soil conditions were observed at the time of drilling of the boreholes. They were logged in the field, and representative samples were taken during the field investigation. This is documented in the boring logs in Appendix B.

Boring W-60-20 was advanced approximately 8 feet east of the wall facing, and loose granular fill was encountered from the top of the boring to a depth of 7 feet. The fill consists of silty sand with scattered organics over poorly graded sand with silt. Underlying the fill, advanced outwash sand layers, alternating with gravel layers in a dense to very dense condition, were encountered for the full depth of the borehole.

Boring W-62mw-20 was advanced approximately 4 feet east of the of wall facing. A 2.5-foot-thick layer of possible fill consisting of poorly graded sand with silt was encountered from the top of the boring. Underneath this fill, advanced outwash sand layers similar to those described for Boring W-60-20 were encountered; however, this boring contained fewer layers of gravel.

3.3 Site Groundwater Conditions

Groundwater conditions were observed at the time of drilling and interpreted from sample moisture content for the boreholes and the elevations, as documented in the boring logs in Appendix B. A groundwater monitoring well was installed in W-62mw-20.

At the time of drilling, both boreholes were dry. A reading in the observation well installed at W-62mw-20 indicated that it was also dry on June 4, 2020. However, from other observation wells in Segment 2A, long-term groundwater in the areas of higher ground elevations were recorded between elevation 86.1 and 91.0 feet (W-138mw-20), and elevation 102.5 and 103.9 feet (W-122mw-20). Accordingly, it appears reasonable to assume that the observation well in W-62mw-20 is too shallow to receive long-term groundwater, since the bottom of the screen is at elevation 111 feet.

To develop engineering recommendations, the groundwater elevation was therefore interpreted to be at elevation 103 feet for the design of wall 9.05R-A. At all times of the year, perched groundwater at higher elevations should be anticipated in response to precipitation patterns, site construction activities, and site utilization. .

4.0 Geologic Hazards

According to the unstable slope assessment (WSDOT 2018b), the area of the project was affected by prehistoric landslides as well as by more recent smaller “landslides associated with over steepened highway cuts and/or poorly constructed embankment slopes.” However, also according to the unstable slope assessment (WSDOT 2018b), the area between milepost 8.66 and milepost 9.42 is free of signs of historic landslides. Wall 9.05R is located near the center of the noted area. This information is supported by the findings in the recent Wood explorations, indicating that the soils in the vicinity of the slope along the east side of the highway consist of medium dense and mostly dense outwash with little susceptibility to deep seated slides.

The seismic design parameters were evaluated for all of Segment 2A. The design calculation package that presents detailed evaluations according to WSDOT-specific project requirements for determining the seismic parameters for wall 9.05R-A can be found in Appendix E-1.1. It was determined that the Segment 2A area should be classified as Site Class C. The seismic parameters for the area are summarized in Table 5 for the Safety Evaluation Earthquake and correspond to a return period of about 1,000 years for the Safety Evaluation Earthquake.

Table 5: Seismic Parameters for Segment 2A, Site Class C – Safety Evaluation Earthquake

Parameter	Return Period
	1,000-year
Site class	C
Peak ground acceleration (PGA)	0.431g
F_{PGA}	1.200
Site-adjusted peak ground acceleration (A_S)	0.517g
Short-period (0.2-second) spectral acceleration (S_S)	0.980g
Site coefficient (F_a)	1.200
Short-period design response acceleration (S_{DS}) = S_S x Fa	1.176g
1-second period spectral acceleration (S_1)	0.283g
Site coefficient (F_v)	1.500
1-second design response acceleration $S_{D1} = S_1 \times F_v$	0.425g

Liquefaction hazard is a soil behavior phenomenon in which a soil loses a substantial amount of strength due to high excess pore-water pressure generated by strong earthquake ground shaking. Recently-deposited (i.e., within about the past 11,000 years) and relatively unconsolidated granular (i.e., non- or low-plasticity) soils and artificial fills located below the groundwater surface are considered potentially susceptible to liquefaction (Idriss and Boulanger, 2008). Based on this site evaluation, the soils are not considered to be susceptible to earthquake-induced liquefaction.

Wall 9.05R-A is a soldier pile wall with soil anchors (where required), which is considered a flexible wall. Seismic deformations of the structure and of the retained soil mass of less than 1.0 to 2.0 inches are anticipated. The horizontal seismic accelerations, k_h, for the overall stability and structural design, were determined in accordance with the *LRFD Bridge Design Specifications* (AASHTO 2017) and in conjunction with the site-specific seismic parameters in Table 5. For seismic movement less than 1.0 inch, the Anderson method of estimating k_h was used. Details of the calculations are provided in Appendix E-1.2.

The following horizontal seismic accelerations (kh) were considered in the design of wall 9.05R-A:

- kh = 0.37 (approximately 0.71As) for an assumed acceptable wall movement of 0.1 inch; and
- kh = 0.26 (approximately 0.5As) for an assumed acceptable wall movement of 1 to 2 inches.

When analyzing global stability and the future wall height of 30 feet, the seismic coefficients were adjusted for a wave scatter factor of 0.82.

5.0 Engineering Stratigraphic Units

The boring logs included in Appendix B provide a detailed description of the soil strata encountered in the subsurface explorations. Table 6 summarizes the assigned ESUs interpreted from the boreholes in the vicinity of wall 9.05R-A. The stratigraphy is shown on Figure A-3 in Appendix A.

Table 6: Summary of ESUs

Assigned ESU	ESU Description
3B	Medium dense Granular ($10 < [N_1]_{60} \leq 30$)
3D	Very Dense Granular ($[N_1]_{60} \geq 50$)

Abbreviations:
ESU = Engineering Stratigraphic Unit
$(N_1)_{60}$ = Standard Penetration Test N-value corrected for effective overburden stress

The ESU soil properties were assigned based on the field and laboratory testing along Segment 2A, and the Geotechnical Soil Properties Methodology report (Wood 2020). Figure A-2 in Appendix A and Figure D-1 in Appendix D describe the ESU soil properties in detail. The methodology is consistent with Chapter 5 of the Project GDM. Given the significant length of Segment 2A and the diversity of the soil conditions, the interpreted design properties at the locations of each structure were adjusted according to the specific local conditions.

The interpreted soil properties for wall 9.05R-A used for the overall limit-equilibrium analysis and drilled shaft design are summarized in Table 7.

The properties described here and in Table 7 also may be used for the soldier pile deformation analyses based on the “p-y” curves approach or approved similar methods. For ESU 3D, a soil modulus k = 225 pounds per cubic foot may be used. In case of the use of LPILE software, the default ‘k’ values may be used.

Both *Geotechnical Engineering Circular* No. 3 (Kavazanjian et al. 2011) and *Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments* (NCHRP 2008) provide recommendations for the values of apparent cohesion that can be assumed for non-cohesive soils above the groundwater table as a function of fines content of the soil. ESU 3D soils at the wall site were found to have a fines content in the range of 7 to 16 percent with an average of less than 10 percent. The average fines content for the entire Segment 2A was 13 percent for ESU 3D. While no grain-size tests were carried out for the ESU 3B soils at this wall site, the average fines content for ESU 3B soil along the entire Segment 2a was 20 percent. Therefore, for evaluation of short-term pseudo-static loading, some apparent cohesion of 50 and 100 pounds per square foot were considered for unsaturated ESU 3D and ESU 3B soils, respectively.

Table 7: Nominal Design Soil Properties for Wall 9.05R-A

ESU	Local Soil Type (USCS Classification)	Range Local Corrected SPT Blow Count, $(N_1)_{60}$ (blows per foot)	Moist Unit Weight (pcf)	ϕ' (deg) [1]	Apparent Cohesion (psf)	Properties for Drilled Shaft Design[1, 2]		
						Effective Friction Angle for Drilled Shaft Design, φ'_f (deg)	N_{60}	σ'_p (ksf)[2]
3B	SP-SM	17 to 18	115	34	100	39	17	9.6
3D	SM; SP-SM; GP-GM	56 to 100	140	42	50	45	80	33.2

Notes:
1. In the case of unsaturated granular soils, drained-effective stress parameters are used for seismic stability analyses.
2. Details for calculation of drilled shaft design parameters are provided in Figures E-3.1 and E-3.2, Appendix E-3.

Abbreviations:

ϕ' = effective peak friction angle
φ'_f = effective soil friction angle for drilled caissons
σ'_p= preconsolidation pressure (Expression 10.8.3.5.2b-4 [AASHTO 2017])
deg = degrees
ESU = Engineering Stratigraphic Unit
ksf = kips per square foot
$(N_1)_{60}$ = SPT N-value corrected for effective overburden stress
N_{60} = SPT N-value corrected for hammer efficiency only
pcf = pounds per cubic foot
psf = pounds per square foot
SPT = Standard Penetration Test
USCS = Unified Soil Classification System

6.0 Design and Recommendations

Retaining wall 9.05R-A will be designed as a soldier pile retaining wall with temporary timber lagging and permanent concrete fascia, as shown on WSDOT Bridge Standard Drawing 8.1-A3-2. The maximum exposed wall height of 18 feet was identified near Sta. 2+60. The detailed structural design will be provided through a separate submittal. Geotechnical recommendations are provided for both a cantilever wall section and an anchored wall section. Geotechnical engineering recommendations also address the forward compatible wall conditions.

The recommendations are based on our interpretation of the subsurface conditions shown in the ESU cross sections and profiles as discussed in Section 5.1, and elevation and/or geometry of the wall as shown in the structural plan sheets.

The static and seismic earth pressures to be considered in the structural design are provided in Figures E-2.12 through E-2.15 in Appendix E-2. They apply along the entire wall length according to the actual geometry of the exposed wall face during temporary construction and permanent conditions. For the global stability analyses in this report, temporary sub-excavations of a maximum of 2 feet below the finished grade were assumed.

6.1 Surcharge Loads on Ground Surface

The area of the backslope behind the wall will be graded and landscaped. Any incidental surcharges at the ground surface may be accounted for in the structural design of the supporting soldier piles. As mentioned in Section 1.0, the loads from NW11 will be applied directly on the soldier piles through a grade beam.

6.2 Lateral Earth Pressures

The earth pressure coefficients used in the preparation of the earth pressure diagrams are shown in Table 8. The active and passive pressure coefficients shown are for a level ground and for inclined backslope as described in the table. Given the nonuniform ground surface at the back of the wall and stratified supported soils, the General Limit Equilibrium (GLE) method was used to determine the static and active seismic horizontal earth pressure coefficients; the GLE results are shown in Appendix E-2, Figures E-2.10 and E-2.11. Once the equilibrium horizontal resisting wall force corresponding to a factor of safety FS=1.0 was obtained from the GLE analysis, the active earth pressure coefficients were determined assuming a linear distribution of the earth pressures in conjunction with an average soil unit weight, γ_a, for the stratified soil deposit calculated as follows:

a) For the exposed height of the wall at the current project phase: $\gamma_a = (140 + 115) / 2 = 128$ pounds per cubic foot
b) For the exposed height at the forward compatibility phase: $\gamma_a = 2*140/3 + 115 / 3 = 132$ pounds per cubic foot

For the cases of sloped ground in the passive zone (foreslope), the passive earth pressure (seismic) coefficients, K_{pe}, in Table 8 have been estimated by prorating the K_{pe} for level ground with the ratio of static passive coefficients for sloping ground and level ground. (i.e., K_p-foreslope/K_p-level ground or 2.7/14.1, respectively).

The static and seismic earth pressure distributions for different cases are provided in Figures E-2.12 through E-2.15. The intensity of the seismic active and passive earth pressure depends on the wall seismic deformations. The structural design should interpolate between the provided seismic earth pressures to select the appropriate pressures consistent with the estimated seismic deformation.

Table 8: Lateral Earth Pressure Coefficients for ESU 3D

Earth Pressure Coefficient	Level Ground	Avg Backslope: 12° (Current Project)	Avg Foreslope: 27° (Current Project)	Avg Backslope: 12° (Future Wall)
Static				
K_a[1]	NA	0.26	NA	0.27
K_p[2]	14.1	NA	2.7	NA
Seismic				
K_{ae} for k_h=0.5A_s*α (1.0 to 2.0 inch movement)[1]	NA	0.39[3]	NA	0.39[4]
K_{ae} for k_h=0.71A_s*α (0.1 inch movement)[1]	NA	0.49[3]	NA	0.46[4]
K_{pe} for k_h=0.50A_s*α (1.0 to 2.0 inch movement)[2]	10.0	NA	1.9	NA
K_{pe} for k_h=0.707A_s*α (0.1 inch movement)[2]	9.4	NA	1.8	NA

Notes:
1. K_a and K_{ae} calculated using the General Limit Equilibrium method (Figures E-2.10 and E-2.11, Appendix E-2) assuming no soil-wall interface friction.
2. K_p and K_{pe} for ESU 3D (φ = 42° and δ= 2/3φ = 28°) and specified k_h using Figures 3.11.5.4-2 and A11.4-2 (AASHTO 2017) (Figure E-2.16, Appendix E-2).
3. α= 1.0 for K_a and K_{pe} in the current project arrangement (exposed structural wall height less than 20 feet).
4. α = 0.82 for K_{ae} and K_{pe} for the future wall, and K_{pe} at current project arrangement corresponding to a total wall and foreslope height of 30 feet.

Abbreviations:
° = degrees
α = wave scatter factor
A_s = site-adjusted peak ground acceleration
ESU = Engineering Stratigraphic Unit
K_a = active earth pressure coefficient (static)
K_{ae} = active earth pressure coefficient (seismic)
k_h = horizontal seismic coefficient
K_p = projected passive earth pressure coefficient (static)
K_{pe} = projected passive earth pressure coefficient (seismic)
NA = not applicable

6.3 Soldier Pile Design

6.3.1 Axial Loads

Geotechnical design of drilled shafts to axial loads should be carried out following the applicable provisions of Section 10.8 of the *LRFD Bridge Design Specifications* (AASHTO 2017).

The shaft tip is expected to be located within ESU 3D material. Accordingly, the nominal tip resistance can be estimated with the expression:

$$q_p = 1.2N_{60} < 60 \text{ kips per square foot}$$

Where: N_{60} (blows/foot) is the average Standard Penetration Test blow count (corrected only for hammer efficiency) in the design zone under consideration.

Based on the anticipated soil conditions of ESU 3D, the predicted unit tip resistance (q_p) is 60 kips per square foot.

The nominal side resistance for shafts in cohesionless soils can be estimated using the expression:

$$q_s = \beta\sigma'_v$$

Where: β is the load transfer factor and σ'_v is the vertical effective stress at soil layer mid-depth, calculated with Expression 10.8.3.5.2b-2 (AASHTO 2017) (See Figure E-3.1, Appendix E-3) and N_{60} from Table 7.

As an example, calculated nominal unit side resistances are shown in Table 9 for the specified embedment ranges of the pile shaft within ESU 4D soils and associated design properties from Table 7. Calculation notes are provided in Appendix E-3.

Side resistance of shafts greater than 20 feet should be estimated as necessary, according to Section 10.8 of the *LRFD Bridge Design Specifications* (AASHTO 2017).

Table 9: Nominal Drilled Shaft Side Resistance for ESU 3D

Embedment Range (feet below grade for the future wall)	σ'_v (psf)	β	q_s (psf)
0 to 7.5	525	5.50	545
7.5 to 10	1225	3.02	1,270
10 to 15	1750	2.35	1,815
15 to 20	2450	1.85	2,540

Abbreviations:
σ'_v = vertical effective stress at soil layer mid-depth
β = load transfer coefficient
q_s = unit side resistance
psf = pounds per square foot

Higher resistances may be used only if proven by load tests.

6.3.2 Lateral Loads

As mentioned in Section 6.2, the active earth pressure coefficients in Table 8 were determined by means of the GLE method.

The static passive earth pressure coefficients below the bottom of the wall toe were assessed using the charts from *LRFD Bridge Design Specifications* (AASHTO 2017) for both level ground and foreslope (see Footnote 2, Table 8). In the case of the seismic coefficient, the AASHTO charts provide coefficients for level ground only. For the sloped ground below the toe of wall, the coefficient K_{pe} was estimated by factoring the seismic coefficient for level ground with the ratio between the static coefficients for sloped ground and level ground.

The soldier pile wall should be designed using the earth pressure diagrams presented in Figures E-2.12 through E-2.15 in Appendix E-2 developed for two levels of anticipated seismic deformations: 0.1 inch and between 1.0 inch and 2.0 inches. The range of the obtained seismic earth pressure coefficients corresponding to these seismic deformations is not large. For seismic deformations estimated between 0.1 and 1.0 inch, interpolation within the provided ranges for K_{ae} and K_{pe} is recommended.

The earth pressures provided are based on the assumption that adequate drainage from surface runoff during precipitation events is provided so that no net or unbalanced hydrostatic pressure develops. Recommendations in this respect are discussed in Section 6.2.7.

Active earth pressure and surcharge pressure from any incidental surcharge on the landscaped area behind the wall should be considered to act over the full pile spacing above the base of the wall. Active pressure below the toe of wall should be considered to act over the diameter of the shaft. Passive earth pressure below the finished grade at the toe of the wall should be considered to act over three pile diameters for static and 2.5 pile diameters for seismic, as detailed in the Project GDM and Chapter 11 of the *LRFD Bridge Design Specifications* (AASHTO 2017).

6.4 Global Slope Stability Analysis Method

Two-dimensional, limit equilibrium analyses were performed based on the method of slices according to Morgenstern-Price's method using Slope/W software from Geo-Slope International, Ltd. Select cases were also checked using the Spencer method. This program employs limit equilibrium methods in accordance with Chapter 7 and Section 15.4.12 of the Project GDM. The input required to carry out a Slope/W analysis, such as slope geometry and material properties, was summarized previously in this report. Trial slip surfaces were created using the entry and exit method. The material properties describe the shear strength of a soil, and are defined by soil unit weight, cohesion, and friction angle. Pore water pressures were specified by piezometric lines. The sections of the ground surface line where the slip surface must enter and exit were selected broadly and then the exit and entry zones were narrowed during subsequent iterations of the analysis. Slope/W computes the factor of safety (FS) for numerous slip surfaces. The slip surface with the lowest FS, or the critical slip surface, is displayed in the results view. This represents the potential sliding mass most likely to exhibit failure based on the input parameters.

Global stability was examined for the cross section listed in Table 1. We evaluated the critical slip surfaces for the static (Strength) limit state loading condition, as well as for the pseudo-static (Extreme 1) limit state for the soldier pile wall. The critical cross section that was analyzed for the wall is shown on Figure A-3 in Appendix A.

A resistance factor of 0.75 (i.e., FS = 1.3) was targeted for the Strength limit state and was used for the global stability analysis in accordance with Project GDM Section 15-4.12. Global stability analysis under the seismic loading targeted a resistance factor of 0.9 (i.e., FS = 1.1). The seismic coefficient, k_h, used in the pseudo-static global stability analyses was determined assuming 1.0 inch to 2.0 inches of seismic deformation of the entire slope.

For the overall stability verification of the soil mass containing the structural components of the wall, the trial slip surfaces were forced to pass at and below the tip of the soldier piles.

For the purposes of the overall stability analyses, a minimum anchor length of 35 feet was selected, based on a bonded length of 15 feet. The bonded length was placed beyond the active wedge, as shown on Figures E-2.13 to E-2.15 in Appendix E-2. However, it should be noted the anchor design will need to consider the most severe loads resulting from both the global stability and internal structural stability based on the recommended earth pressures.

The output figures from our global stability analyses augmented with details on assumptions, discussion and recommendations are provided in the calculation package (Appendix E-2) associated with the wall. Slope/W input and output files are provided in Appendix E-4. The results are summarized in Table 10.

297 **Table 10: Stability Analysis Results – Station 2+60 of Wall 9.05R-A**

Analysis		FS	Remarks	Figure[1]
1	Verification of soldier pile minimum embedment at future compatibility (Static)	2.0	A minimum embedment of 5 feet below the anticipated future temporary cut was considered and checked along a potential slip surface passing below the shaft tips. The FS > 1.3 indicates sufficient stability against the noted failure mechanism and minimum pile shaft embedment considered. Deeper embedment may be necessary to meet the soldier pile requirements to support the loads of the retaining wall, the noise wall, and the vertical projection of the anchor loads. Static loads from NW11 modeled by a net shear force of 500 lbs/ft and a set of complementary point loads of 8,500 pounds spaced at 1.0 foot distance to model the factored overturning moment.	E-2.1
2	Global stability of the soil mass containing the wall (Long-Term Static)	2.3	Higher value of FS is due to significant wall embedment in the present wall arrangement. Static loads from NW11 modeled as above (Analysis 1).	E-2.2
3	Global stability of the soil mass containing the wall (Pseudo-static assuming 1.0 to 2.0 inches slope and wall seismic movement)	1.7	A higher FS than minimum required due to the pile embedment for the future wall arrangement. A net shear force of 2,400 lbs/ft and overturning moment of 47,000 lbs*ft/ft modelled by two complementary point loads of 47,000 pounds spaced at 1.0 foot distance were included at the top of retaining wall/base of noise wall to account for the seismic loads from NW11 sitting on top of the soldier pile wall.	E-2.3
4	Project arrangement: through-wall – Service 1 (Static) using M-P and Spencer method	1.3	Analysis conducted to assess the minimum unfactored shear wall and anchor pullout resistances necessary to develop the required FS=1.3 for global stability along slip surfaces crossing the wall and anchors. The resistances obtained (2,000 lbs/ft for each of the resisting components) represent only one of the multiple combinations possible. No changes in results between M-P and Spencer methods.	E-2.4 and E-2.5
5	Project Arrangement-Extreme 1: Using the pseudo-static slope approach (M-P method)	1.1	Pseudo-static slope model with a seismic coefficient k_h = 0.21, determined on the basis of a seismic slope and wall movement of 1.0 to 2.0 inches. The analysis illustrates one of the multiple possible combinations of the resistances required for the pile shaft and anchor is 1,600 lbs/ft for each resisting component using the M-P analysis method.	E-2.6

Analysis		FS	Remarks	Figure[1]
6	Similar to Analysis 5 using Spencer method	1.1	Analysis conducted as a cross-check of Analysis 5 by a different method as per Project GDM. In this case, the Spencer method led to tangibly increased demands for the combination anchor resistances (from 1,600 lbs/ft to 2,900 lbs/ft) and pile shaft resistances (from 1,600 lbs/ft to 2,500 lbs/ft) over the M-P method. This scenario governs the anchor and shaft design for global stability. However, other combinations of structural resistances of the pile shaft and anchors may be available to ensure the required factor of safety for global stability as illustrated in Analyses 7 and 8.	E-2.7
7	Similar to Analysis 6 example of different structural resistance designs	1.1	Same as Analysis 6 using a different combination of strength imparted to the pile shaft (2,400 lbs/ft) and anchor pullout resistance (3,000 lbs/ft), leading to same FS=1.1 for the global stability under seismic loads using the Spencer method.	E-2.8
8	Similar to Analysis 5 example using cantilevered wall arrangement	>1.3 Static 1.1 Seismic	This is an illustration for a cantilever arrangement. Seismic case dictates the design requiring an increased shaft resistance to 5,100 lbs/ft. The shaft embedment shown is valid for the global stability. The actual embedment may need to be increased subject to structural design of the cantilevered wall. The cantilever option for exposed wall face exceeding 10 feet in height may not be practical for permanent structures due to potential for significant static deformation. Subject to acceptance of the wall deformation performance assessed by the structural design, the shaft embedment may need to be increased beyond the length shown herein subject to the shaft structural design to lateral loads.	E-2.9

Notes:

1. Figures referenced are located in Appendix E-2.

Abbreviations

FS = factor of safety
GDM = Geotechnical Design Manual
GLE = General Limit Equilibrium
K_a = active earth pressure coefficient (static)
K_{ae} = active earth pressure coefficient (seismic)
lbs/ft = pounds per foot
lbs*ft/ft = pound-foot per unit length of wall
M-P = Morgenstern-Price
NW11 = noise wall 11

The global stability analyses results indicate that the Extreme limit state controls the design for global stability.

6.5 Soil Anchors

6.5.1 Pullout Capacity

For preliminary design, the resistance of the anchor may be based on the presumptive ultimate unit bond stress, as given in Table C11.9.4.2.2 (AASHTO 2017). These were used to determine the relevant values shown in Table 11, which are based on an assumed drilled diameter of 6 inches.

Table 11: Soil Anchor Pullout Capacity

Anchor Type (Grout Pressure)	Soil	Presumptive Ultimate Bond Strength (kips/foot)[1]
Gravity Grouted Anchors (<50 psi) Sand or Sand-Gravel Mix	Medium Dense Fine to Medium Sand (ESU 3B)	2.75
Gravity Grouted Anchors (<50 psi) Sand or Sand-Gravel Mix	Dense to Very Dense Fine to Sand (ESU 3D)	4.60

Notes:

1. Presumptive ultimate bond strength values are based on presumptive ultimate bond stresses of 1.75 ksf and 2.9 ksf for ESU 3B and ESU 3D, respectively, as shown in Table C11.9.4.2.2 (AASHTO 2017). Higher ultimate unit bond stresses may be obtained in case of pressure grouted anchors.

Abbreviations:

ESU = Engineering Stratigraphic Unit
kip = 1,000 pounds
ksf = kips per square foot
psi = pounds per square inch

6.5.2 Corrosion

Permanent ground anchors shall have double corrosion protection, consisting of an encapsulation-protected tendon bond length as specified in the WSDOT General Special Provisions.

6.5.3 Anchor Stressing and Testing

All production anchors shall be subjected to load testing and stressing in accordance with the *WSDOT Standard Specifications* (WSDOT 2018C) and the *Bridge Design Manual* Article 8.1.5 (WSDOT 2019).

6.6 Strength Limit State Resistance Factors

The resistance factors in Table 12 should be used for permanent retaining walls.

Table 12: Strength Resistance Factors for Permanent Soldier Pile Wall

Limit State	Condition	Resistance Factor
Strength I	Passive Resistance of Vertical Elements	0.75[1]
Strength I	Flexural Capacity of Vertical Elements	0.9[1]
Service I	Displacements	1.0[2]
Strength I	Pullout Resistance of Anchors (Cohesionless soils)[1, 3]	0.65[1, 3]
Strength I	Pullout Resistance of Anchors (where proof tests are conducted)[1, 4]	1.0[1,4]
Strength I	Axial Compressive Resistance Soldier Pile: Side Resistance in Cohesionless Soils	0.55[5]
Strength I	Axial Compressive Resistance Soldier Pile: Tip Resistance in Cohesionless Soils	0.50[5]

Notes:

1. Resistance factors as per Table 11.5.7-1 (AASHTO 2017).
2. Resistance factor as per Section 11.5.7 (AASHTO 2017).
3. Applicable only to presumptive ultimate unit bond stresses for preliminary design given only in Section C11.9.4.2 (AASHTO 2017).
4. Apply where proof tests are conducted on every production anchor to a load of 1.0 times or greater times the factored load on the anchor.
5. Resistance factor as per Table 10.5.5.2.4.-1 (AASHTO 2017).

6.7 Soldier Pile Settlements

Based on the empirical load-transfer functions provided in Chapter 10 (AASTO 2017), settlement of the soldier piles designed according to the recommendations in this report and founded within undisturbed ESU 3D soils are anticipated not to exceed 0.5 percent of the concrete shaft diameter. This estimate does not include the elastic shortening of the H piles.

6.8 Soldier Pile Installation

Soldier pile walls include vertical steel H-piles typically spaced about 6 to 8 feet on center, to be determined by the structural engineer designing the wall. The piles are installed by drilling to the required depth. After placement of the H-pile, the drilled hole is filled with controlled density fill or structural concrete, depending on the design. At wall 9.05R-A, the groundwater is anticipated to be near elevation 103 feet; however, seepage of perched groundwater may occur at higher elevations. In these cases, construction of the soldier piles may require the use of temporary casing.

The temporary lagging shall be designed for Soil Type 1 as outlined in Standard Specifications Section 6-16.3(6)A (WSDOT 2018c). It is recommended that the lagging be designed for the uniform static pressures indicated in Figures E-2.12 through E-2.15 in Appendix E-2.

6.9 Compaction Behind the Wall

Wherever required, compaction energy should be limited, and hand-operated compaction equipment should be considered when compacting fill within about 5 feet of wall.

If any backfill is needed, WSDOT-specified Gravel Backfill for Walls per the Standard Specifications (WSDOT 2018c) shall be used behind the wall.

If workers need to be directly below the temporary cut slope to achieve compaction, then the cut will need to be sloped per the Occupational Safety and Health Administration standards for Soil Type C. The site conditions shall be verified during construction and the cut slope shall be engineered or temporarily shored.

6.10 Drainage

A suitable drainage system should be installed to prevent the buildup of hydrostatic pressures behind the soldier pile and lagging wall. Drainage for temporary timber lagging, if used, can be achieved by spacing the lagging with a vertical gap of approximately 1/8 to 1/4 inch. The standard WSDOT drainage details shown on WSDOT Bridge Standard Drawing 8.1-A3-5 are adequate for providing drainage. The space behind the lagging should be backfilled with free-draining material as soon as practical.

7.0 General Construction and Maintenance Considerations

In addition to the design recommendations, the following construction and maintenance concerns shall be implemented as applicable.

7.1 Utilities and Overhead Clearance

Prior to construction, the Contractor shall verify the location of buried and overhead utilities (such as overhead/buried power, telecommunication, and water lines, etc.) within the limit of work, and relocate the utilities as needed. Existing utility trenches, if present, typically are loosely compacted and could pose challenges for construction, especially for soil cuts.

7.2 Surface Water and Groundwater

Based on the groundwater measurements (see Section 3.3, Site Groundwater Conditions), temporary dewatering of groundwater is not anticipated during the installation of the lagging. Temporary erosion and sediment control plans, implementation, and maintenance will be needed to prevent surface water and sediment from affecting adjacent areas.

7.3 Temporary Slopes and Shoring

The wall construction may require temporary slopes and/or shoring at some locations (e.g., to prepare working platforms from the installation of the soldier piles). Design of temporary cut slopes and shoring will be provided by the project Contractor and should be reviewed by the Wood Geotechnical Group Manager. All excavation work shall comply with local, state, and federal safety codes. The soils are considered to be Type B. Per Section 15.7 in the Project GDM and based on Section 2-09.3(3)B in the WSDOT Standard Specifications (WSDOT 2018c), open temporary cuts shall meet following requirements:

- No vehicular or construction traffic or construction surcharge loads will be allowed within 5 feet of the top of the cut.
- Exposed soil along the slope shall be protected from surface erosion.
- Construction activities shall be scheduled so that the length of time the temporary cut is left open is reduced to the extent practical.
- Surface water shall be diverted away from the excavation.

7.4 Construction

Continuous inspection by the geotechnical engineer or their representative is required during soldier pile drilling and installation, as well as tieback anchor installation and testing.

7.5 Maintenance

Retaining walls require typical maintenance throughout their lifetime. The wall will have typical drainage through the wall to prevent hydrostatic pressure. These drainage systems need to be maintained.

Permanent slopes require periodic maintenance of vegetation and erosion control.

8.0 References

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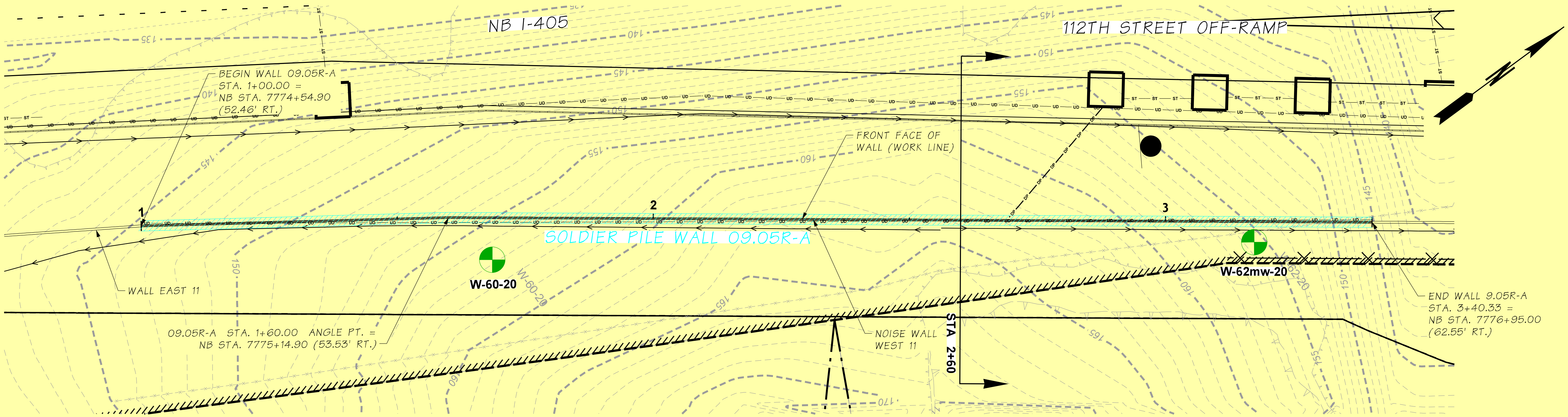
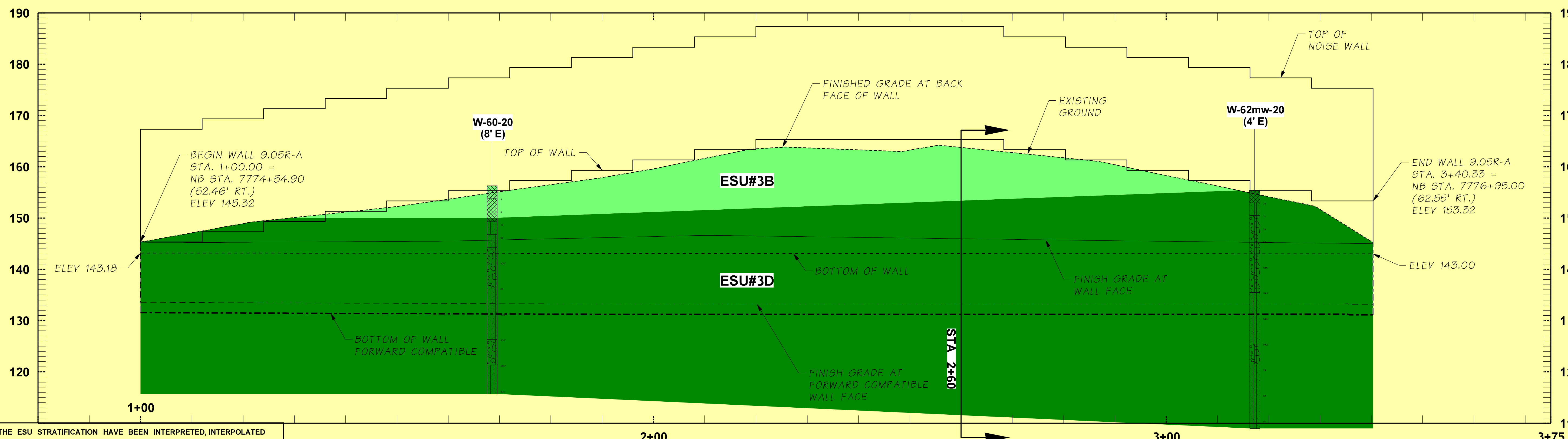
In Association with

Appendix A
Wall Design Plan Sheets and
ESU Cross Sections and Profiles



PLAN - WALL 09.05R-A



REFLECTIVE ELEVATION - WALL 09.05R-A

THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES. THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.

LEGEND: BOREHOLE LOCATION (WOOD)
(See ESU description in Figure A-2)

NOTE: INTERPRETED GROUNDWATER TABLE NEAR EL. 103.0 BASED ON OTHER OBSERVATION WELLS AWAY FROM THE WALL

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TIME	5:29:31 PM
DATE	3/16/2021
PLOTTED BY	stephen.labute
DESIGNED BY	D. DIMITRIU
ENTERED BY	S. LABUTE
CHECKED BY	M. RADIC
PROJ. ENGR.	T. WENTWORTH
REGIONAL ADM.	T. NETTLETON

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

FLATIRON LANE

wood.

I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT
SOLDIER PILE WALL

RETAINING WALL PLAN AND PROFILE
WALL 09.05R-A

PLAN REF NO

1 OF 1

Figure A-1

Table 1 - ESU Definitions & Soil Property Summary Along Segment 2A

ESU	Description	Total Number of Samples	N60 (bpf)		$N_1$60 (bpf)		Saturated Unit Weight, γ_s (pcf)		Average Fines Content	ϕ' (deg)[a]		Fully Softened ϕ' (deg)[d,f,p]		Residual ϕ' (deg)[f,p]		ϕ' (deg) FHWA Drilled Shafts		Effective Cohesion, c' (psf)		Plasticity Index, PI (%)	
			Value	COV	Value	COV	Value[b]	COV[c]	%	Value[b]	COV[c]	Value	COV[c]	Value	COV[c]	Value[b]	COV[c]	Value[b]	COV[c]	Value	COV
ESU 1	Project Fill (new) - PLACEHOLDER	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2A	Peat	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2B	Granular with organics[k]	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2C	Fines with organics or organic fines[k]	9	24	0.86[m,n]	27	0.79[m,n]	95[h]	--	68[o]	31[l]	--	--	--	--	--	NA	--	0	--	15[o]	--
ESU 3A	Loose granular (N160<=10)	31	6	0.41	7	0.39	110	0.08	28	29	0.12	--	--	--	--	35	0.10	--	--	NA	--
ESU 3B	Med dense granular (10<N160<=30)	165	17	0.34	19	0.29	115	0.03	20	34	0.06	--	--	--	--	39	0.03	--	--	NA	--
ESU 3C	Dense granular (30<N160<50)	108	36	0.32	40	0.16	135	0.02	18	38	0.04	--	--	--	--	42	0.01	--	--	NA	--
ESU 3D	Very dense granular (N160>=50)	315	80	0.25	80	0.22	140	0.00	13	42	0.03	--	--	--	--	45	0.01	--	--	NA	--
ESU 4A	Soft to medium stiff fines (N160<=8)	15	6	0.28	6	0.25	105	0.05	81	31	0.02	28	0.05	--	--	NA	--	0	--	20	0.54
ESU 4B.1	Medium stiff to stiff fines (high plasticity - MH,CH) (8<N160<=15)	29	15	0.32	13	0.15	115	0.03	94	27	0.04	25	0.10	--	--	NA	--	0	--	37	0.20
ESU 4B.2	Medium stiff to stiff fines (low plasticity - ML,CL) (8<N160<=15)	45	14	0.47[m]	12	0.18	115	0.04	68	32	0.03	27	0.10	--	--	NA	--	0	--	15	0.51
ESU 4C	Very stiff to hard fines - intact (high plasticity - MH,CH) (N160>15)	117	28	0.55[m]	26	0.51[m]	125	0.02	94	24	0.09	24	0.09	--	--	NA	--	577	0.17	34	0.29
ESU 4D	Very stiff to hard fines - intact (low plasticity - ML,CL) (N160>15)	436	36	0.51[m]	33	0.50[m]	130	0.02	79	29	0.07	26	0.07	--	--	NA	--	627	0.00	13	0.40
ESU 4E	Very stiff to hard fines - disturbed (high plasticity - MH,CH) (N160>15)[e]	24	25	0.43	25	0.42	125	0.02	92	23	0.09	23	0.09	16	0.21	NA	--	514	0.26	39	0.31
ESU 4F	Very stiff to hard fines - disturbed (low plasticity - ML,CL) (N160>15)[e]	55	34	0.54[m]	35	0.59[m]	125	0.02	69	28	0.09	28	0.09	21	0.11	NA	--	627	0.00	17	0.41
ESU 5A	Landslide deposits - granular	8	9	0.86[n]	11	0.89[n]	110	0.18[n]	30[g]	31[j]	0.26	--	--	--	--	37[j]	0.22[n]	--	--	--	--
ESU 5B	Landslide deposits - fines	11	22	0.42	24	0.41	120	0.03	82[i]	31[j]	--	29	0.01	22	0.04	NA	--	0[j]	0.00	19	0.19

Notes:
a. Reported friction angle for coarse grained from Figure 7 of the Soil Properties Methodology (SPM) memo (after table 5.1 in WSDOT GDM). Coarse grained friction angles have been reduced by approximately 1 degree per 5% of fines for fines contents between 5% and 30%. Reported friction angle for fine grained units from Figure 8 (after Terzaghi 1996) or Equations 4 and 5 (after Sorensen and Okkels, 2013) of the SPM.
b. Design value calculated using representative N1(60) or PI value for each ESU.
c. Coefficient of Variation reported for property distribution after calculating property value for each SPT sample within the soil unit.
d. Fully softened friction angles were calculated using only samples with AL reported.
e. "Disturbed" defined as samples with notes of disturbance, slickensides, fractures, and/or blocky structure on the boring logs. Soils with coarse grained classifications with these descriptors were ignored, as well as soft to stiff fines (i.e., ESUs 4A to 4B.2). If a unit had disturbance descriptors *and* landslide debris descriptors, that sample was placed in ESU 5.
f. Softened and residual friction angle estimated using the following assumptions: where a grain size analysis was available, the percent fines was assumed to equal the clay fraction. Where a grain size analysis was not available, the percent fines was estimated using the USCS descriptor. Where Atterberg Limits (AL) were available, liquid limits (LL) from the AL were used. Fully softened and residual friction angles were calculated using only samples with AL reported.
g. All samples in ESU 5A are visually classified as an SM on the boring log. No grain size available. Percent fines assumed from USCS classification.
h. The unit weight for ESU 2C was assumed to be the average of the minimum and maximum values presented in Figure 3 of the SPM.
i. Average of the fines contents from ESUs 4A to 4F used as the Average Fines Content for 5B.
j. Friction angle has not been reduced to account for landslide deposition. The fines-adjusted granular correlation was used for 5A, and fine-grained normally consolidated correlation was used for 5B. Effective cohesion has been ignored for 5B.
k. Any samples with notes of numerous or abundant organics, or identified as an organic soil (OL, OH), were placed into ESUs 2B and 2C.
l. Values have not been reduced to account for organics.
m. COVs are out of the specified range for SPT blowcount, but do not significantly affect the design properties as the friction angle and effective cohesion is a function of plasticity index and not blowcount.
n. COVs are out of the specified range, but not enough samples to further break down units. Would not meet the minimum of 3 to 5 samples per SPM.
o. No grain size or AL reported for samples in ESU 2C. samples primarily consist of OL and ML. Assume similar percent fines and PI as ESU 4B.2.
p. Fully softened or residual friction angles will be updated or replaced where local hydrometer testing is completed.

for reference (Fig 1 from SPM)...

Measured or interpreted parameter value	Coefficient of Variation, V (%)
Unit weight, γ	3 to 7 %
Buoyant unit weight, γ_b	0 to 10 %
Effective stress friction angle, ϕ'	2 to 13 %
Undrained shear strength, s_u	13 to 40 %
Undrained strength ratio (s_u/σ_v')	5 to 15 %
Compression index, C_c	10 to 37 %
Preconsolidation stress, σ_p'	10 to 35 %
Hydraulic conductivity of saturated clay, k	68 to 90 %
Hydraulic conductivity of partly-saturated clay, k	130 to 240 %
Coefficient of consolidation, c_v	33 to 68 %
Standard penetration blowcount, N	15 to 45 %
Electric cone penetration test, q_c	5 to 15 %
Mechanical cone penetration test, q_c	15 to 37 %
Vane shear test undrained strength, s_{uVST}	10 to 20 %

Figure 1: Values of coefficient of variation, V, for geotechnical properties and in situ tests (after Duncan, 2000) (see Duncan, 2000 for original references on reported values of V)

Source: Table 52 (Sabatini et al. 2002)

Table 2 - Site Specific Strength Tests[a]

Boring ID	Test Depth (ft)	ESU	Test Type
W-56-20	15.7	4D or 4F	3 Point Isotropic CU
W-70-20	19.0	4C	Isotropic CU
W-148	20.6	4D[b]	CRS, UU
W-148	62.5	4C or 4E[b]	CRS, UU
W-148	92.0	4D	CRS, UU

Notes:
a. Table 2 is for reference only. Values presented in Table 2 have not been incorporated in the segment properties presented in Table 1 above.
b. Lab testing incomplete. ESU final designation dependent on final lab testing.

FILE NAME	09.35L-R01001.dwg		
TIME			
DATE			
PLOTTED BY			
DESIGNED BY	D. DIMITRIU		
ENTERED BY	S. LABUTE		
CHECKED BY	M. RADIC		
PROJ. ENGR.	T. WENTWORTH		
REGIONAL ADM.	T. NETTLETON	REVISION	DATE BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XL5467

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

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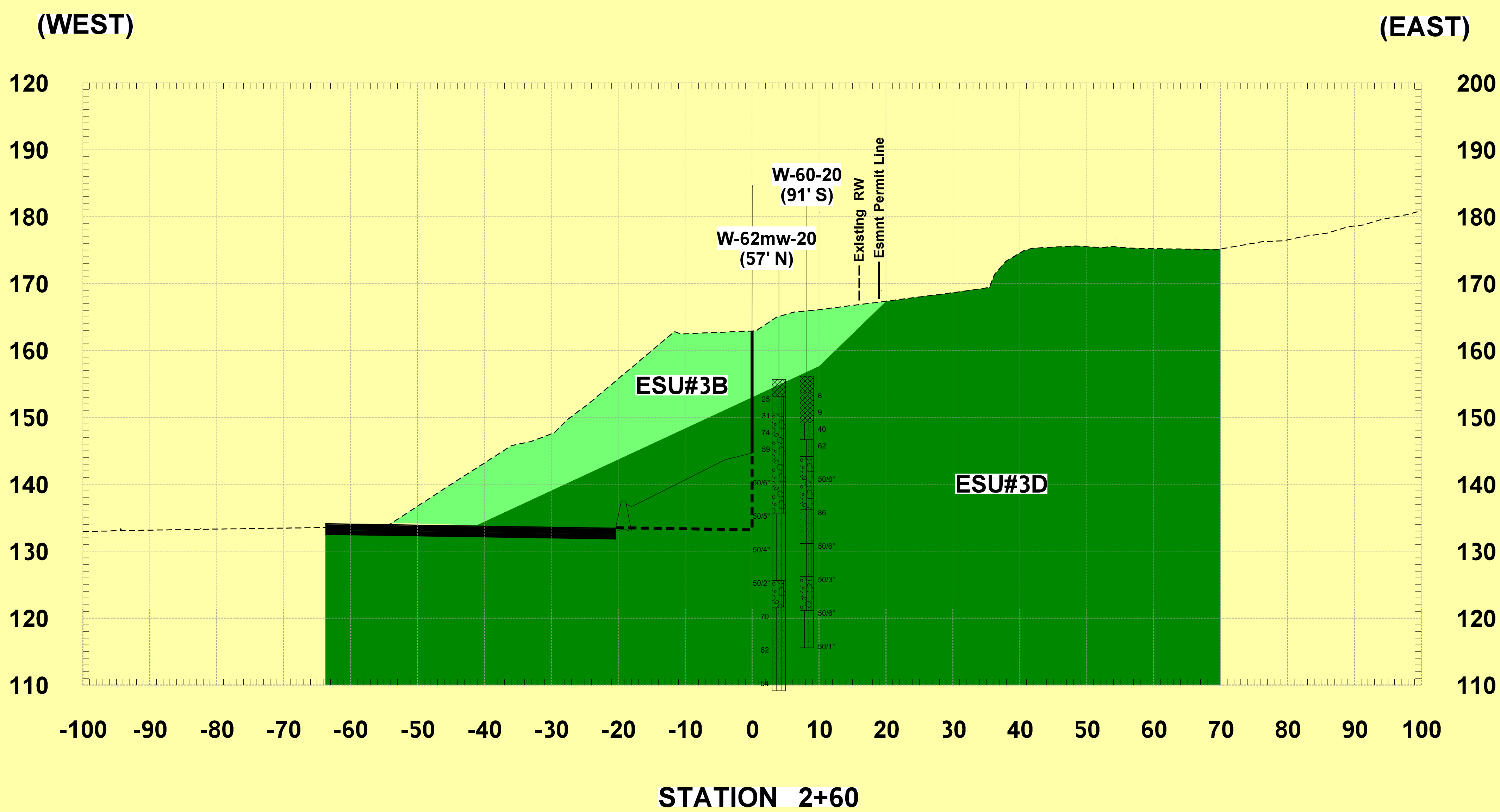
I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT SEGMENT 2A

ESU DEFINITION ALONG SEG. 2A

PLAN REF NO

1 OF 1

Figure A-2



THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES. THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.

NOTE: INTERPRETED GROUNDWATER TABLE NEAR EL. 103.0 BASED ON OTHER OBSERVATION WELLS AWAY FROM THE WALL

(See ESU description in Figure A-2)

FILE NAME	c:\users\stephen.labute\documents\projectwise\workingdir\wsdot\dms16518\Wall 09.05R-A ESU_Sta2+60.dgn
TIME	5:25:00 PM
DATE	3/16/2021
PLOTTED BY	stephen.labute
DESIGNED BY	D. DIMITRIU
ENTERED BY	S. LABUTE
CHECKED BY	M. RADIC
PROJ. ENGR.	T. WENTWORTH
REGIONAL ADM.	T. NETTLETON

REVISION | DATE | BY

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	

JOB NUMBER

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

FLATIRON LANE

wood.

I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT RETAINING WALL 09.05R-A

CROSS-SECTION STA 2+60

PLAN REF NO

1 OF 1

Figure A-3

In Association with

Appendix B
Field Exploration Procedures and Logs

Appendix B: Field exploration procedures

The following paragraphs describe the procedures used for field explorations and field tests that Wood conducted for this project. Descriptive logs of our explorations are enclosed in this appendix.

Auger boring procedures

Most of the exploratory borings were advanced with a hollow-stem auger using a track-mounted drill rig operated by an independent drilling firm working under subcontract to Wood. An engineering geologist from Wood continuously observed the borings, logged the subsurface conditions, and collected representative soil samples. All samples were stored in watertight containers and later transported to the laboratory for further visual examination and testing. After each boring was completed, the borehole was backfilled with a mixture of bentonite chips and soil cuttings, and the surface was patched with asphalt or concrete (where appropriate).

Throughout the drilling operation, soil samples were obtained at 2.5- or 5-foot depth intervals by means of the Standard Penetration Test (SPT) per ASTM D-1586. This testing and sampling procedure consists of driving a standard 2-inch-diameter steel split-spoon sampler 18 inches into the soil with a 140-pound hammer free-falling 30 inches. The number of blows required to drive the sampler through each 6-inch interval was counted, and the total number of blows struck during the final 12 inches was recorded as the Standard Penetration Resistance, or “SPT blow count.” If a total of 50 blows were struck within any 6-inch interval, the driving was stopped and the blow count was recorded as 50 blows for the actual penetration distance. The resulting Standard Penetration Resistance values indicate the relative density of granular soils and the relative consistency of cohesive soils.

The enclosed boring logs describe the vertical sequence of soils and materials encountered in each boring, based primarily on field classifications and supported by subsequent laboratory examination and testing. Where a soil contact was observed to be gradational, boring logs indicate the average contact depth. Where a soil type changed between sample intervals, we inferred the contact depth. The boring logs also graphically indicate the blow count, sample type, sample number, and approximate depth of each soil sample obtained from the borings, as well as any laboratory tests performed on these soil samples. If any groundwater was encountered in a borehole, the approximate groundwater depth is depicted on the boring log. Groundwater depth estimates are typically based on the moisture content of soil samples, the wetted height on the drilling rods, and the water level measured in the borehole after the auger has been extracted.

Mud rotary drilling procedures

Where conducted, exploratory borings were advanced with mud rotary using a track-mounted drill rig operated by an independent drilling firm working under subcontract to Wood. An engineering geologist from Wood continuously observed the borings, logged the subsurface conditions, and collected representative soil samples. All samples were stored in watertight containers and later transported to the laboratory for further visual examination and testing. After each boring was completed, the borehole was backfilled with a mixture of bentonite chips and soil cuttings, and the surface was patched with asphalt or concrete (where appropriate).

Throughout the drilling operation, soil samples were obtained at 2.5- or 5-foot depth intervals by means of the SPT per ASTM D-1586. This testing and sampling procedure consists of driving a standard 2-inch-diameter steel split-spoon sampler 18 inches into the soil with a 140-pound hammer free-falling 30 inches. The number of blows required to drive the sampler through each 6-inch interval was counted, and the total number of blows struck during the final 12 inches was recorded as the Standard Penetration Resistance, or “SPT blow count.” If a total of 50 blows were struck within any 6-inch interval, the driving was stopped and the blow count was recorded as 50 blows for the actual penetration distance. The resulting Standard Penetration Resistance values indicate the relative density of granular soils and the relative consistency of cohesive soils.

The enclosed boring logs describe the vertical sequence of soils and materials encountered in each boring, based primarily on field classifications and supported by subsequent laboratory examination and testing. Where a soil contact was observed to be gradational, boring logs indicate the average contact depth. Where a soil type changed between sample intervals, we inferred the contact depth. The boring logs also graphically indicate the blow count, sample type, sample number, and approximate depth of each soil sample obtained from the borings, as well as any laboratory tests performed on these soil samples. If any groundwater was encountered in a borehole, the approximate groundwater depth is depicted on the boring log. Groundwater depth estimates are typically based on the moisture content of soil samples, the wetted height on the sampling spoon, and the water level measured in the borehole after the auger has been extracted, although the drilling mud makes it difficult to determine groundwater levels accurately at the time of drilling.

Field Soil Description

wood.

ORDER OF CLASSIFICATION TERMS

1. Soil classification
2. Relative density/consistency
3. Color (based on Munsell Color Chart)
4. Moisture
5. Structure
6. Other - plasticity, dilatancy, organics, odor

Geologic Name: Fill, Glacial Till, etc. (optional - ask project manager)

EXAMPLES

Well graded GRAVEL, with cobbles and boulders, subrounded, medium dense, grayish brown, wet, homogeneous, no HCL reaction or HCL not tested (Alluvium) SM

Silty fine SAND with gravel, prevalent roots and fine organics, subrounded, loose, brownish black, moist, no HCL reaction or HCL not tested (Relict Topsoil) SM

Fibrous or amorphous PEAT with or without some silt/clay; PT

Fat CLAY with sand, medium stiff, dark gray, wet, blocky, no HCL reaction or HCL not tested (Lawton Clay) CH

RELATIVE DENSITY OF GRANULAR SOILS (Cohesionless Silt, Sand, and Gravel)

N, SPT, BLOWS/FT	RELATIVE DENSITY	FIELD TEST FOR RELATIVE DENSITY OF SAND*
0-4	Very loose	Penetrated 3 feet or more by hand probe
4-10	Loose	Penetrated 1 to 2 feet by hand probe
11-24	Med-dense	Penetrated 3 to 12 inches by hand probe
25-50	Dense	Penetrated 1 to 3 inches by hand probe
Over 50	Very Dense	Penetrated less than 1 inch by hand probe * varies with soil type

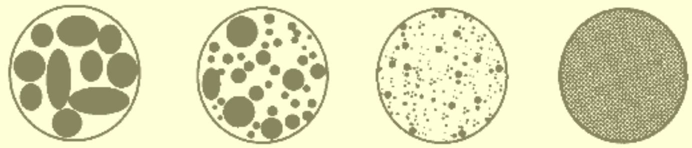
RELATIVE CONSISTENCY OF COHESIVE SOILS (Cohesive, Silt, and Clay)

N, SPT, BLOWS/FT	RELATIVE DENSITY	TORVANE, tsf SHEAR STR.	POC. PEN., tsf UNCONF. STR.	MANUAL PENETRATION TEST
0-1	Very soft	<0.13	<0.25	Easy several inches by fist
2-4	Soft	0.13 - 0.25	0.25 - 0.5	Easy several inches by thumb
5-8	Medium stiff	0.25 - 0.5	0.5 - 1	Moderate several inches by thumb
9-15	Stiff	0.5 - 1	1 - 2	Readily indented by thumb
16-30	Very stiff	1 - 2	2 - 4	Readily Indented by thumbnail
30-60	Hard	>2	>4	Difficulty by thumbnail

SOIL STRUCTURE

Stratified	Alternating layers of varying material or color with layers at least 6mm (1/4") thick
Laminated	Alternating layers of varying material or color with layers less than 6 mm (1/4") thick
Seam	2 to 13 mm (1/16" - 1/2") thick
Layer	13 to 305 mm (1/2" - 12") thick
Occasional	One or less per foot of thickness
Frequent	More than one per foot of thickness
Fissured	Breaks along definite planes of fracture with little resistance to fracturing
Slickensided	Fracture planes appear to be polished or glossy, sometimes striated
Blocky	Cohesive soil that can be broken down into small angular lumps which resist further breakdown
Lensed	Inclusion of small pockets of different soils, generally discontinuous, such as small lenses of sand through out a mass of clay; note thickness.
Homogeneous	Same color and appearance throughout

GRAIN SIZE



Coarse Sand | Medium Sand | Fine Sand | Fine <#200

UNIFIED SOIL CLASSIFICATION SYSTEM (From ASTM D-2488 & 2487-90)

MAJOR DIVISIONS			GROUP SYMBOL	TYPICAL DESCRIPTION
Coarse-Grained Soils (more than 50% retained on No. 200 sieve)	Gravels (more than 50% of coarse fraction retained on No. 4 sieve)	Clean Gravels (less than 10% fines)	GW	Well-Graded Gravels, Gravel-Sand Mixtures, Little or No Fines
			GP	Poorly-Graded Gravels, Gravel-Sand Mixutres
		Gravels with Fines (>10% fines)	GM	Silty Gravels, Gravel-Sand-Silt Mixtures
			GC	Clayey Gravels, Gravel-Sand-Clay Mixtures
	Sands (50% or more of coarse fraction passes the No. 4 sieve)	Clean Sands (<10% fines)	SW	Well-Graded Sands, Gravelly Sands, Little or No Fines
			SP	Poorly-Graded Sand, Gravelly Sands, Little or No Fines
		Sands with Fines (>10% fines)	SM	Silty Sands, Sand-Silt Mixtures
			SC	Clayey Sands, Sand-Clay Mixtures
Fine-Grained Soils (50% or more passes the No. 200 sieve)	Silts and Clays (liquid limit less than 50)	Inorganic	ML	Inorganic silts and Very Fine Sands, Rock Flour, Silty or Clayey Fine Sands or Clayey Silts with Slight Plasticity
			CL	Inorganic Clays of Low to Medium Plasticity, Gravelly Clays, Sandy Clays, Silty Clays, Lean Clays
		Organic	OL	Organic Silts and Organic Silty Clays of Low Plasticity
	Silts and Clays (liquid limit 50 or more)	Inorganic	CH	Inorganic Clays of Medium to High Plasticity, Sandy Fat Clay, Gravelly Fat Clay
			MH	Inorganic Silts, Micaceous or Diatomaceous Fine Sands or Silty Soils, Elastic Silt
		Organic	OH	Organic Clays of Medium to High Plasticity, Organic Silts
Highly Organic Soils	Primarily organic matter, dark in color, and organic ordor		PT	Peat, Humus, Swamp Soils with High Organic Content (See D 4427-92)

MOISTURE CONTENT

Dry - Dusty, dry to touch

Moist - Damp but no visible water

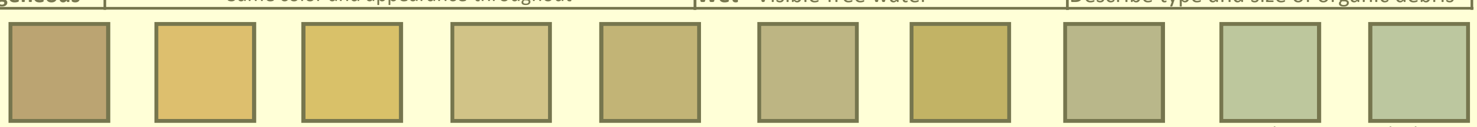
Wet - Visible free water

ORGANIC CONTENT

ADJECTIVE	PERCENT BY VOLUME
Scattered	1 - 10
Numerous	10 - 30
Organic	30 - 50 minor constituent
PEAT	50 - 100 MAJOR constituent

Describe type and size of organic debris

MUNSELL COLORS:



Reddish Brown | Brownish Yellow | Olive Yellow | Light Yellow Brown | Light Olive Brown | Grayish Brown | Olive | Grey | Greenish Gray | Bluish Grey

MAJOR DIVISIONS			SYMBOLS GRAPH	SYMBOLS LETTER	TYPICAL DESCRIPTIONS
COARSE GRAINED SOILS	GRAVEL AND GRAVELLY SOILS	CLEAN GRAVELS		GW	WELL-GRADED GRAVELS, GRAVEL - SAND MIXTURES, LITTLE OR NO FINES
		(LESS THAN 5% FINES)		GP	POORLY-GRADED GRAVELS, GRAVEL - SAND MIXTURES, LITTLE OR NO FINES
	MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	GRAVELS WITH FINES		GM	SILTY GRAVELS, GRAVEL - SAND - SILT MIXTURES
		(GREATER THAN 12% FINES)		GC	CLAYEY GRAVELS, GRAVEL - SAND - CLAY MIXTURES
	SAND AND SANDY SOILS	CLEAN SANDS		SW	WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES
MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE		(LESS THAN 5% FINES)		SP	POORLY-GRADED SANDS, GRAVELLY SAND, LITTLE OR NO FINES
	MORE THAN 50 OF COARSE FRACTION PASSING NO. 4 SIEVE	SANDS WITH FINES		SM	SILTY SANDS, SAND - SILT MIXTURES
		(GREATER THAN 12% FINES)		SC	CLAYEY SANDS, SAND - CLAY MIXTURES
FINE GRAINED SOILS	SILTS AND CLAYS	INORGANIC		ML	INORGANIC SILTS AND VERY FINE SANDS, ROCK FLOUR, SILTY OR CLAYEY FINE SANDS OR CLAYEY SILTS WITH SLIGHT PLASTICITY
				CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, SILTY CLAYS, LEAN CLAYS
	LIQUID LIMIT LESS THAN 50	ORGANIC		OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	INORGANIC		MH	INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SAND OR SILTY SOILS
				CH	INORGANIC CLAYS OF HIGH PLASTICITY
	LIQUID LIMIT GREATER THAN 50	ORGANIC		OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS				PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS
FILL SOILS				FILL (AF)	HUMAN ALTERED SOIL OR MODIFIED LAND

NOTES:

1. SOIL DESCRIPTIONS ARE BASED ON THE GENERAL APPROACH PRESENTED IN THE STANDARD PRACTICE FOR DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE), AS OUTLINED IN ASTM D 2488. WHERE LABORATORY INDEX TESTING HAS BEEN CONDUCTED, SOIL CLASSIFICATIONS ARE BASED ON THE STANDARD TEST METHOD FOR CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES, AS OUTLINED IN ASTM D 2487.
2. SOIL DESCRIPTION TERMINOLOGY IS BASED ON VISUAL ESTIMATES (IN THE ABSENCE OF LABORATORY TEST DATA) OF THE PERCENTAGES OF EACH SOIL TYPE AND IS DEFINED AS DESCRIBED BELOW:
3. DUAL SYMBOLS (E.G. SP-SM, OR GP-GM) ARE USED TO INDICATE A SOIL WITH AN ESTIMATED 5-12% FINES.

PRIMARY CONSTITUENT: >50% - "GRAVEL", "SAND", "SILT", "CLAY", etc.
SECONDARY CONSTITUENTS: >12% and ≤50% - "gravelly", "sandy", "silty", etc.
ADDITIONAL CONSTITUENTS: >5% and ≤12% - "some gravel", "some sand", "some silt", etc.
≤5% - "trace gravel", "trace sand", "trace silt" etc. or not noted.

4. RELATIVE DENSITY OF SOIL IS BASED ON STANDARD TEST METHOD FOR PENETRATION TEST (SPT) AND SPLIT-BARREL SAMPLING OF SOILS ASTM D 1586 OR CORRELATIONS FOR OTHER SIMPLER TYPES AND METHODS FOR SPT SAMPLING, THE FOLLOWING BLOW COUNT CORRELATION APPLIES.

A. RELATIVE DENSITY OF COARSE GRAINED SOILS (N = BLOWS/FOOT SPT METHOD)
- VERY LOOSE: N = ≤4
- LOOSE: N = >4 AND ≤10
- MEDIUM DENSE: N = >10 AND ≤30
- DENSE: N = >30 AND ≤50
- VERY DENSE: N = >50

B. RELATIVE CONSISTENCY OF FINE GRAINED SOILS (N = BLOWS/FOOT SPT METHOD)
- VERY SOFT: N = <2
- SOFT: N = ≥2 AND ≤4
- MEDIUM STIFF: N = >4 AND ≤8
- STIFF: N = >8 AND ≤15
- VERY STIFF: N = >15 AND ≤30
- HARD: N = >30

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Kirkland, Washington 98033

SOIL CLASSIFICATION CHART / KEY

DATE JUNE 2018
SCALE NOT TO SCALE
PROJECT NO.
FIGURE B-1

DRAWN BY: JRS CHECKED BY: JD

wood.
4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-60-20
CLIENT WSDOT **PROJECT LOCATION** Renton, WA
DATE STARTED 5/13/20 **COMPLETED** 5/13/20 **GROUND ELEVATION** 156.3 ft NAVD88 **HOLE SIZE** 8 inches
DRILLING CONTRACTOR Gregory Drilling **DRILL RIG** CME 55 ID: #310 **SPT HAMMER EFFICIENCY** 88%
DRILLING METHOD HSA **STATION (FT)** 5779+83.91 **OFFSET (FT)** 156.4 R
LOGGED BY Carlos Mendoza **CHECKED BY** H Brenniman **NORTHING** 204958.136 **EASTING** 1304953.182
NOTES Soil Nail Wall 09.05R **GW LEVEL (ATD)** Dry

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
	0		Silty SAND, loose, reddish brown, moist, with scattered organics and tree roots, [Fill] (SM)				
155							
			Poorly graded SAND with silt, loose, reddish to yellowish brown, moist, [FILL/Qva] (SP-SM)	33	SPT-1 3 3 5	8	
	5			56	SPT-2 5 4 5	9	
150							
			Silty SAND, dense, yellowish brown, moist, [Qva] (SM)	50	SPT-3 17 18 22	40	MC = 6%
	10		Poorly graded SAND with silt and gravel, very dense, yellowish brown, moist, [Qva] (SP-SM)	72	SPT-4 11 25 34	59	MC = 4% Fines = 7%
145							
			Poorly graded GRAVEL with silt and sand, very dense, yellowish brown, moist, [Qva] (GP-GM)				Gravelly drilling at 12 feet
	15			50	SPT-5 11 43 50	50/6"	
140							
	20						

(Continued Next Page)

wood.
4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-60-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ / PL MC LL / ☐ FINES CONTENT (%) ☐	TESTS AND REMARKS
	20		Poorly graded SAND with silt and gravel, very dense, yellowish brown, moist, [Qva] (SP-SM)	50	SPT-6 23 48 38	86	
135							
	25		Poorly graded SAND with silt, very dense, dark yellowish brown, moist, [Qva] (SP-SM)	78	SPT-7 14 28 50	50/6"	MC = 5% Fines = 7%
130							
	30		Poorly graded GRAVEL with silt and sand, very dense, light olive brown, moist, [Qva] (GP-GM)	67	SPT-8 37 50/3"	50/3"	
125							
	35		Silty SAND with gravel, very dense, light olive brown, dry to moist, [Qva] (SM)	67	SPT-9 50	50/6"	MC = 3%
120							
	40			86	SPT-10 40 50/1"	50/1"	

Bottom of borehole at 40.6 feet.

wood.

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-62mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

DATE STARTED 5/13/20 **COMPLETED** 5/14/20 **GROUND ELEVATION** 155.5 ft NAVD88 **HOLE SIZE** 8 inches

DRILLING CONTRACTOR Gregory Drilling **DRILL RIG** CME 55 ID: #310 **SPT HAMMER EFFICIENCY** 88%

DRILLING METHOD HSA **Well Tag #** BLE-770 **STATION (FT)** 5781+32.38 **OFFSET (FT)** 165.53 R

LOGGED BY Carlos Mendoza **CHECKED BY** H. Brenniman **NORTHING** 205079.873 **EASTING** 1305038.659

NOTES **GW LEVEL (ATD)** Dry **GW LEVEL (6/4/2020)** Dry

ELEVATION (ft)	DEPTH	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE	TESTS AND REMARKS
155	0	Poorly graded SAND with silt and gravel, medium dense, reddish brown, moist, [Fill] (SP)				
		Silty SAND, dense, yellowish brown, dry to moist, [Qva] (SM)	39	SPT-1 4 9 16	25	
150	5	Poorly graded SAND with silt and gravel, dense, yellowish brown, moist, [Qva] (SP-SM)	17	SPT-2 6 10 21	31	
		Becomes very dense	67	SPT-3 13 31 41	72	MC = 4% Fines = 7%
145	10		44	SPT-4 10 28 31	59	
140	15		50	SPT-5 18 50	50/6"	
	20					

Chart scales: ▲ SPT N VALUE ▲ 20 40 60 80; PL MC LL 20 40 60 80; ☐ FINES CONTENT (%) ☐ 20 40 60 80

WELL DIAGRAM

(Continued Next Page)

wood.
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Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-62mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE / PL MC LL / FINES CONTENT (%)	TESTS AND REMARKS
135	20	Silty SAND with gravel, very dense, yellowish brown, moist, [Qva] (SM)	55	SPT-6 8 50/5"	50/5"	MC = 5%
130	25		60	SPT-7 28 50/4"	50/4"	
125	30	Poorly graded GRAVEL with sand, very dense, yellowish brown, moist, [Qva] (GP)	75	SPT-8 25 50/2"	50/2"	
		Silty SAND, very dense, yellowish brown, moist, [Qva] (SM)				
120	35		61	SPT-9 18 30 40	70	MC = 7% Fines = 16%
115	40		67	SPT-10 18 26 36	62	

(Continued Next Page)

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-62mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	WELL DIAGRAM	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / □ FINES CONTENT (%) □ 20 40 60 80	TESTS AND REMARKS
			Silty SAND, very dense, yellowish brown, moist, [Qva] (SM) *(continued)*					
110	45			78	SPT-11 10 26 28		54	MC = 6%

Bottom of borehole at 46.5 feet.

In Association with

Appendix C
Laboratory Testing Procedures and Results

In Association with

Appendix C: Laboratory testing procedures

This appendix describes procedures associated with the laboratory tests Wood assigned for this project. Geotechnical laboratory testing was performed by a local, accredited geotechnical testing laboratory, subcontracted to Wood. Results of certain laboratory tests are enclosed in this appendix.

Visual classification procedures

Visual soil classifications were conducted on all samples in the field and on selected samples in the laboratory. All soils were classified in general accordance with the Unified Soil Classification System, which includes color, relative moisture content, primary soil type (based on grain size), and any accessory soil types. The resulting soil classifications are presented on the exploration logs contained in Appendix B.

Moisture content determination procedures

Moisture content determinations were performed on representative samples to aid in identification and correlation of soil types. All determinations were made in general accordance with ASTM D-2216. The results of these tests are shown on the exploration logs contained in Appendix B.

Grain-size analysis procedures

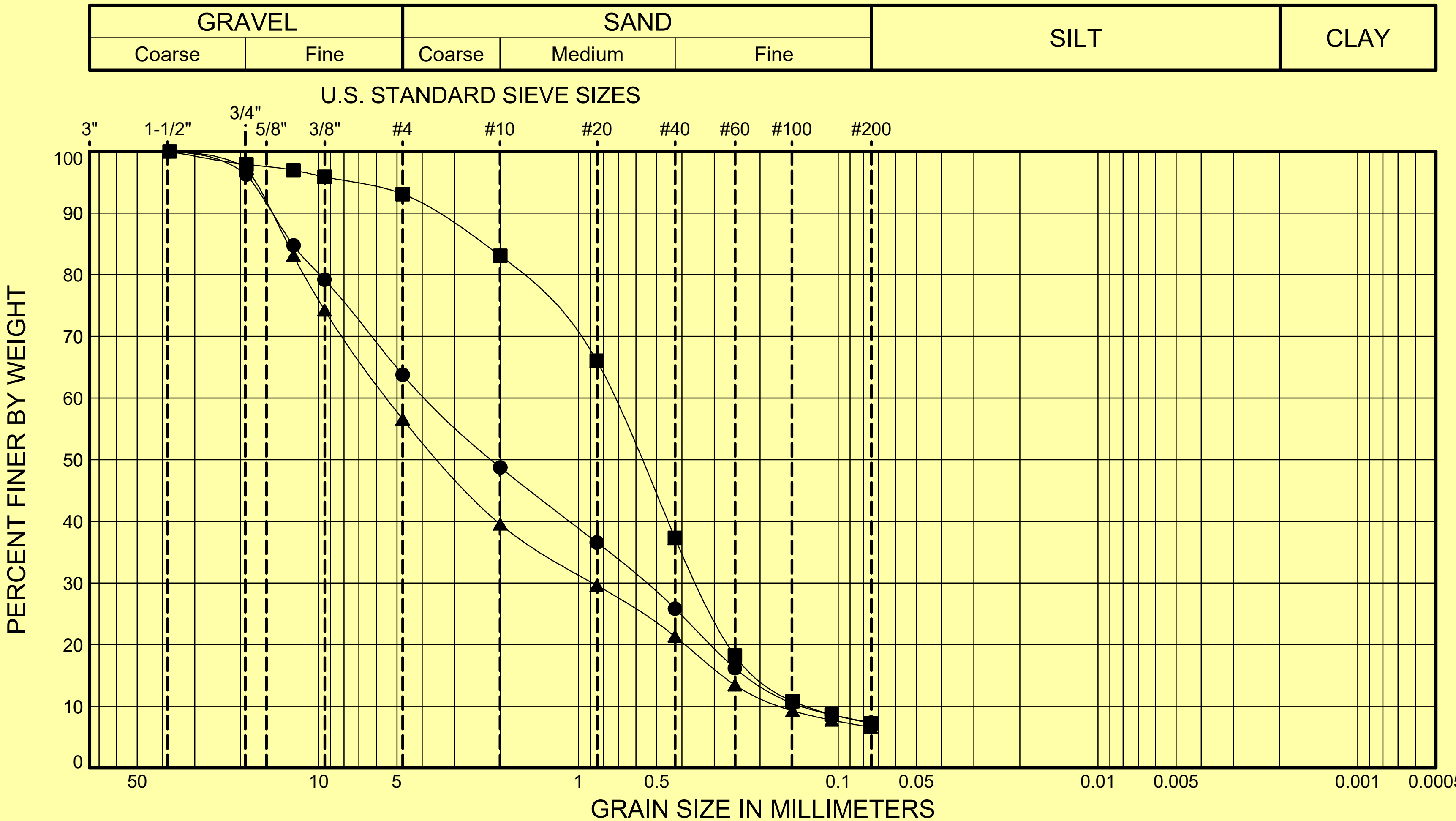
A grain-size analysis indicates the range of soil particle diameters included in a particular sample. Grain-size analyses were performed on representative samples in general accordance with ASTM D-422. The results of these tests are presented on the enclosed grain-size distribution graphs and were used in soil classifications shown on the exploration logs contained in Appendix B.

Atterberg limit determination procedures

Atterberg limits are used primarily for classifying and indexing cohesive soils. The liquid and plasatic limits, which are defined as the moisture contents of a cohesive soil at arbitrarily established limits for liquid and plastic behavior, were determined for selected samples in general accordance with ASTM D-4318. The results of these tests are presented on the enclosed Atterberg limit graphs and on the boring logs contained in Appendix B.

No. “200-Wash” analysis procedures

A “200-wash” is a procedure in which the fine-grained soil fraction is seprated from the sand and gravel by washing the soil on a U.S. No. 200 sieve. A “200-wash” analysis was performed on selected soil samples obtained from our explorations in general accordance with ASTM D-1140. The results of these analyses is presented in the enclosed grain size graphs and were used in our soil classifications shown on the exploration logs contained in Appendix B.



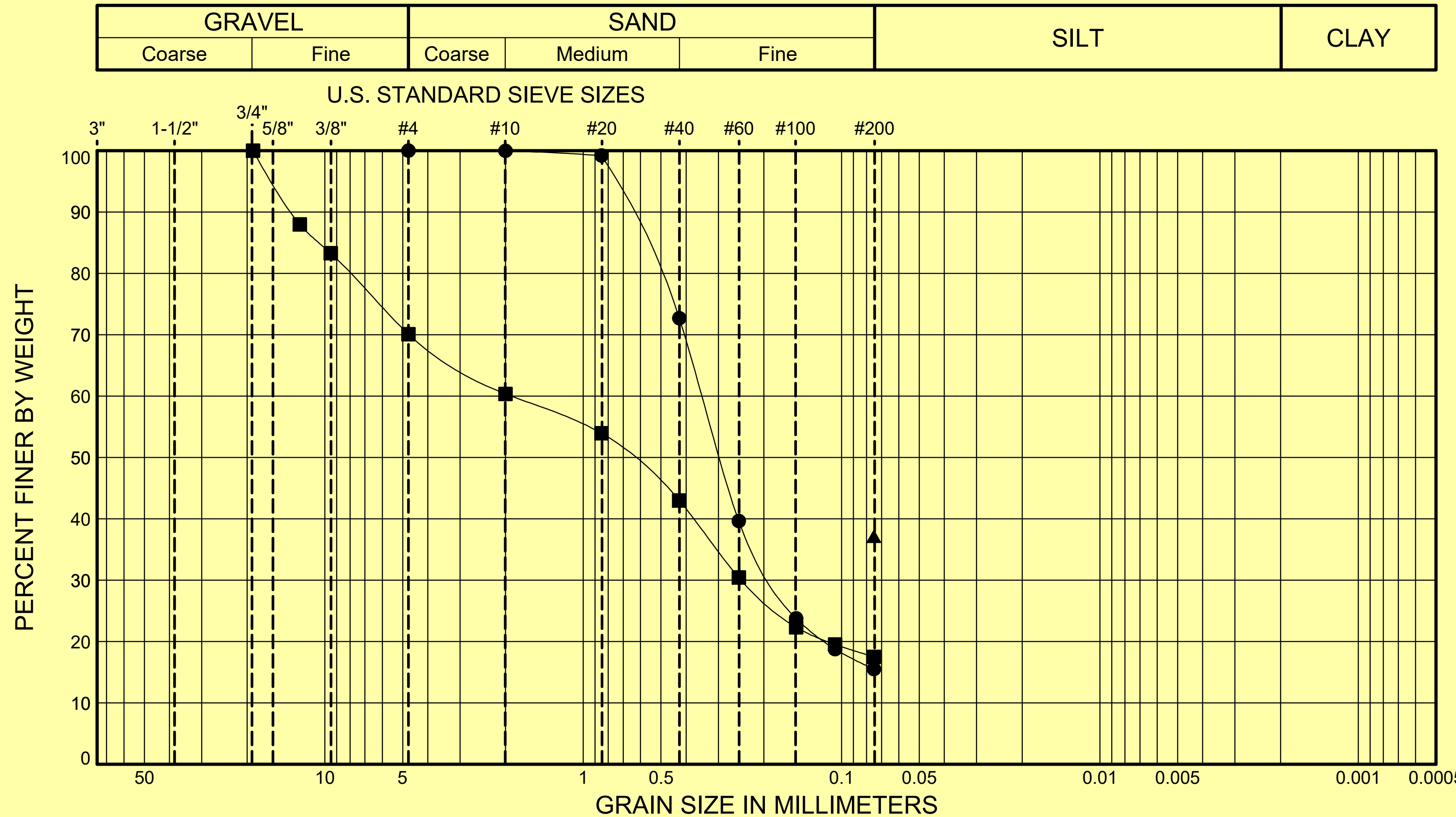
SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-060-20	S-4	10.0 - 11.5	(SP-SM) Light olive-brown, poorly graded SAND with silt and gravel	4				36.2	56.4	7.3
■	W-060-20	S-7	25.0 - 26.5	(SP-SM) Olive-brown, poorly graded SAND with silt	5				6.9	85.8	7.2
▲	W-062MW-20	S-3	7.5 - 9.0	(SP-SM) Light olive-brown, poorly graded SAND with silt and gravel	4				43.4	49.9	6.6

HWA GEOSCIENCES INC.

I-405 Renton to Bellevue
Widening and Express Toll Lanes
Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS OF SOILS METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 3



SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-062MW-20	S-9	35.0 - 36.5	(SM) Light olive-brown, silty SAND	7					84.5	15.5
■	W-063-20	S-3	7.5 - 9.0	(SM) Olive-brown, silty SAND with gravel	8				29.9	52.6	17.5
▲	W-063-20	S-6	20.0 - 21.5	(SM) Olive-brown, silty SAND	14						37.1

HWA GEOSCIENCES INC.

I-405 Renton to Bellevue
Widening and Express Toll Lanes
Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 4

In Association with

Appendix D
ESU Soil Properties

Appendix D – ESU Soil Properties

This appendix describes procedures associated with the assignment of soil properties based on laboratory tests, field exploration, and soil property methodology. The data from the borehole logs and laboratory tests were imported into our spreadsheet and associated (N1)60 values were calculated.

Stratigraphic unit grouping

Geologic strata as defined in Section 5.2 of the Project GDM were identified based on review of the available borehole logs, laboratory testing and published geologic maps. Geologic cross sections were initially developed using the interpreted geologic strata. A geotechnical engineer then assigned Engineering Stratigraphic Units (ESUs) based on review of the geologic cross sections, grouping geologic strata with similar engineering properties.

Evaluate Statistical Analysis

The (N1)60 parameters were accumulated for each ESU. The average, geomean, and standard deviation were calculated for

(N1)60. The blow count values were evaluated for outliers that are associated with mislabeling, testing errors, and statistics. The outliers were either reassigned to another ESU, remained in the statistical evaluation, or were removed from the statistical valuation. The blow counts vs depth chart, standard deviations, and covariance were utilized to make these assessments. The covariance was verified to be between 15 and 45 percent per the LRFD Bridge Design Specifications (AASHTO 2017).

Review Soil Property Values

Soil properties were assigned per the Geotechnical Soil Properties Methodology report (Wood 2020).

In most cases, the effective friction angle was assigned to the ESU group in accordance with Table 5-1 in the Project GDM using the average (N1)60 value. Within the range of values presented in Table 5-1, information on the fines content and soil plasticity was also considered to assign the effective friction angle. Values at or near the upper limit of Table 5-1 were selected when fines content was determined as below 5 percent passing U.S. sieve No.200. Values at or near the lower limit were selected for soil with “significant” fines, taken as soil with fines content greater than 30 percent passing US No.200 sieve, based on the 2014 Caltrans Geotechnical Manual. For samples where the fines content was between 5 and 30 percent, interpolation was used between the upper and lower limit to select the effective friction angle. For low plasticity fine grained material, material with a plasticity index less than 5, Table 5-1 was used to determine the effective friction angle using lower limit in comparison with the value that was derived based on the plasticity index value as referenced in the Geotechnical Soil Properties Methodology report (Wood 2020). In circumstances where the ESU has high covariance and outside the soil parameters for the referenced volume of Engineering Geology in Washington, then the lower or higher value will be chosen.

The unit weight for each ESU was determined based on the Caltrans (2014) method of USCS classification with blow counts. The value for unit weight was compared to the ranges in Coduto (2001) and the Project GDM for verification. If the unit weight is outside the range of the reference documents, then the value will be adjusted to fit within the range.

Other soil engineering properties were determined based on results of Cone Penetrometer Test probes, laboratory testing and correlations as described in the Geotechnical Soil Properties Methodology report (Wood 2020).

Table 1 - ESU Definitions & Soil Property Summary Along Segment 2A

ESU	Description	Total Number of Samples	N60 (bpf)		$N_1$60 (bpf)		Saturated Unit Weight, γ_s (pcf)		Average Fines Content	ϕ' (deg)[a]		Fully Softened ϕ' (deg)[d,f,p]		Residual ϕ' (deg)[f,p]		ϕ' (deg) FHWA Drilled Shafts		Effective Cohesion, c' (psf)		Plasticity Index, PI (%)	
			Value	COV	Value	COV	Value[b]	COV[c]	%	Value[b]	COV[c]	Value	COV[c]	Value	COV[c]	Value[b]	COV[c]	Value[b]	COV[c]	Value	COV
ESU 1	Project Fill (new) - PLACEHOLDER	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2A	Peat	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2B	Granular with organics[k]	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
ESU 2C	Fines with organics or organic fines[k]	9	24	0.86[m,n]	27	0.79[m,n]	95[h]	--	68[o]	31[l]	--	--	--	--	--	NA	--	0	--	15[o]	--
ESU 3A	Loose granular (N160<=10)	31	6	0.41	7	0.39	110	0.08	28	29	0.12	--	--	--	--	35	0.10	--	--	NA	--
ESU 3B	Med dense granular (10<N160<=30)	165	17	0.34	19	0.29	115	0.03	20	34	0.06	--	--	--	--	39	0.03	--	--	NA	--
ESU 3C	Dense granular (30<N160<50)	108	36	0.32	40	0.16	135	0.02	18	38	0.04	--	--	--	--	42	0.01	--	--	NA	--
ESU 3D	Very dense granular (N160>=50)	315	80	0.25	80	0.22	140	0.00	13	42	0.03	--	--	--	--	45	0.01	--	--	NA	--
ESU 4A	Soft to medium stiff fines (N160<=8)	15	6	0.28	6	0.25	105	0.05	81	31	0.02	28	0.05	--	--	NA	--	0	--	20	0.54
ESU 4B.1	Medium stiff to stiff fines (high plasticity - MH,CH) (8<N160<=15)	29	15	0.32	13	0.15	115	0.03	94	27	0.04	25	0.10	--	--	NA	--	0	--	37	0.20
ESU 4B.2	Medium stiff to stiff fines (low plasticity - ML,CL) (8<N160<=15)	45	14	0.47[m]	12	0.18	115	0.04	68	32	0.03	27	0.10	--	--	NA	--	0	--	15	0.51
ESU 4C	Very stiff to hard fines - intact (high plasticity - MH,CH) (N160>15)	117	28	0.55[m]	26	0.51[m]	125	0.02	94	24	0.09	24	0.09	--	--	NA	--	577	0.17	34	0.29
ESU 4D	Very stiff to hard fines - intact (low plasticity - ML,CL) (N160>15)	436	36	0.51[m]	33	0.50[m]	130	0.02	79	29	0.07	26	0.07	--	--	NA	--	627	0.00	13	0.40
ESU 4E	Very stiff to hard fines - disturbed (high plasticity - MH,CH) (N160>15)[e]	24	25	0.43	25	0.42	125	0.02	92	23	0.09	23	0.09	16	0.21	NA	--	514	0.26	39	0.31
ESU 4F	Very stiff to hard fines - disturbed (low plasticity - ML,CL) (N160>15)[e]	55	34	0.54[m]	35	0.59[m]	125	0.02	69	28	0.09	28	0.09	21	0.11	NA	--	627	0.00	17	0.41
ESU 5A	Landslide deposits - granular	8	9	0.86[n]	11	0.89[n]	110	0.18[n]	30[g]	31[j]	0.26	--	--	--	--	37[j]	0.22[n]	--	--	--	--
ESU 5B	Landslide deposits - fines	11	22	0.42	24	0.41	120	0.03	82[i]	31[j]	--	29	0.01	22	0.04	NA	--	0[j]	0.00	19	0.19

Notes:
a. Reported friction angle for coarse grained from Figure 7 of the Soil Properties Methodology (SPM) memo (after table 5.1 in WSDOT GDM). Coarse grained friction angles have been reduced by approximately 1 degree per 5% of fines for fines contents between 5% and 30%. Reported friction angle for fine grained units from Figure 8 (after Terzaghi 1996) or Equations 4 and 5 (after Sorensen and Okkels, 2013) of the SPM.
b. Design value calculated using representative N1(60) or PI value for each ESU.
c. Coefficient of Variation reported for property distribution after calculating property value for each SPT sample within the soil unit.
d. Fully softened friction angles were calculated using only samples with AL reported.
e. "Disturbed" defined as samples with notes of disturbance, slickensides, fractures, and/or blocky structure on the boring logs. Soils with coarse grained classifications with these descriptors were ignored, as well as soft to stiff fines (i.e., ESUs 4A to 4B.2). If a unit had disturbance descriptors *and* landslide debris descriptors, that sample was placed in ESU 5.
f. Softened and residual friction angle estimated using the following assumptions: where a grain size analysis was available, the percent fines was assumed to equal the clay fraction. Where a grain size analysis was not available, the percent fines was estimated using the USCS descriptor. Where Atterberg Limits (AL) were available, liquid limits (LL) from the AL were used. Fully softened and residual friction angles were calculated using only samples with AL reported.
g. All samples in ESU 5A are visually classified as an SM on the boring log. No grain size available. Percent fines assumed from USCS classification.
h. The unit weight for ESU 2C was assumed to be the average of the minimum and maximum values presented in Figure 3 of the SPM.
i. Average of the fines contents from ESUs 4A to 4F used as the Average Fines Content for 5B.
j. Friction angle has not been reduced to account for landslide deposition. The fines-adjusted granular correlation was used for 5A, and fine-grained normally consolidated correlation was used for 5B. Effective cohesion has been ignored for 5B.
k. Any samples with notes of numerous or abundant organics, or identified as an organic soil (OL, OH), were placed into ESUs 2B and 2C.
l. Values have not been reduced to account for organics.
m. COVs are out of the specified range for SPT blowcount, but do not significantly affect the design properties as the friction angle and effective cohesion is a function of plasticity index and not blowcount.
n. COVs are out of the specified range, but not enough samples to further break down units. Would not meet the minimum of 3 to 5 samples per SPM.
o. No grain size or AL reported for samples in ESU 2C. samples primarily consist of OL and ML. Assume similar percent fines and PI as ESU 4B.2.
p. Fully softened or residual friction angles will be updated or replaced where local hydrometer testing is completed.

for reference (Fig 1 from SPM)...

Measured or interpreted parameter value	Coefficient of Variation, V (%)
Unit weight, γ	3 to 7 %
Buoyant unit weight, γ_b	0 to 10 %
Effective stress friction angle, ϕ'	2 to 13 %
Undrained shear strength, s_u	13 to 40 %
Undrained strength ratio (s_u/σ_v')	5 to 15 %
Compression index, C_c	10 to 37 %
Preconsolidation stress, σ_p'	10 to 35 %
Hydraulic conductivity of saturated clay, k	68 to 90 %
Hydraulic conductivity of partly-saturated clay, k	130 to 240 %
Coefficient of consolidation, c_v	33 to 68 %
Standard penetration blowcount, N	15 to 45 %
Electric cone penetration test, q_c	5 to 15 %
Mechanical cone penetration test, q_c	15 to 37 %
Vane shear test undrained strength, s_{uVST}	10 to 20 %

Figure 1: Values of coefficient of variation, V, for geotechnical properties and in situ tests (after Duncan, 2000) (see Duncan, 2000 for original references on reported values of V)

Source: Table 52 (Sabatini et al. 2002)

Table 2 - Site Specific Strength Tests[a]

Boring ID	Test Depth (ft)	ESU	Test Type
W-56-20	15.7	4D or 4F	3 Point Isotropic CU
W-70-20	19.0	4C	Isotropic CU
W-148	20.6	4D[b]	CRS, UU
W-148	62.5	4C or 4E[b]	CRS, UU
W-148	92.0	4D	CRS, UU

Notes:
a. Table 2 is for reference only. Values presented in Table 2 have not been incorporated in the segment properties presented in Table 1 above.
b. Lab testing incomplete. ESU final designation dependent on final lab testing.

FILE NAME	09.35L-R01001.dwg
TIME	
DATE	
PLOTTED BY	
DESIGNED BY	D. DIMITRIU
ENTERED BY	S. LABUTE
CHECKED BY	M. RADIC
PROJ. ENGR.	T. WENTWORTH
REGIONAL ADM.	T. NETTLETON

REVISION | DATE | BY

REGION NO. 10 | STATE WASH | FED.AID PROJ.NO.

JOB NUMBER XL5467

CONTRACT NO. | LOCATION NO.

P.E. STAMP BOX | DATE

P.E. STAMP BOX | DATE

Washington State Department of Transportation

FLATIRON LANE

wood.

I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT SEGMENT 2A

ESU DEFINITION ALONG SEG. 2A

PLAN REF NO

1 OF 1

Figure D-1

Soil unit ID	2C	Fines with organics or organic fines
Total Samples	9	

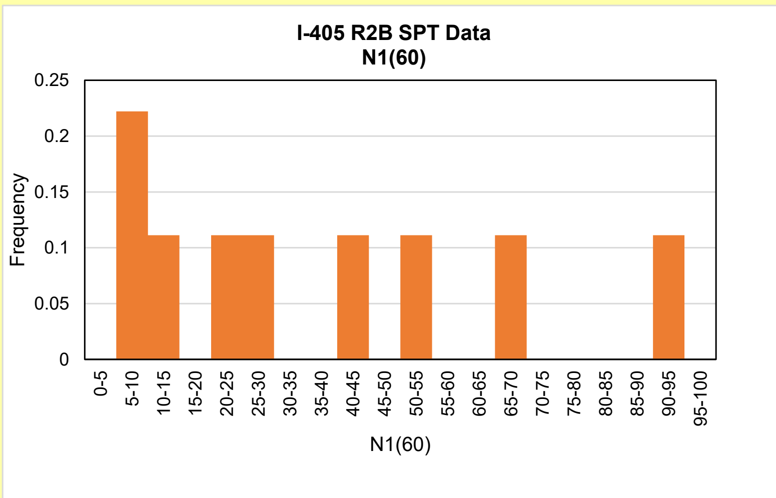
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	7	7	7	7	0	0	0	0	0	0
Max	95	95	93	93	0	0	0	0	0	0
Average	35	35	37	37	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Geomean	24	24	27	27						#NUM!
StDev	30	30	29	29						#DIV/0!
15th Percentile	7	7	8	8						#NUM!
85th Percentile										#NUM!
COV	0.86	0.86	0.79	0.79						#DIV/0!
Count	9	9	9	9	0	0	0	0	0	0
Design Value		24		27			68			15

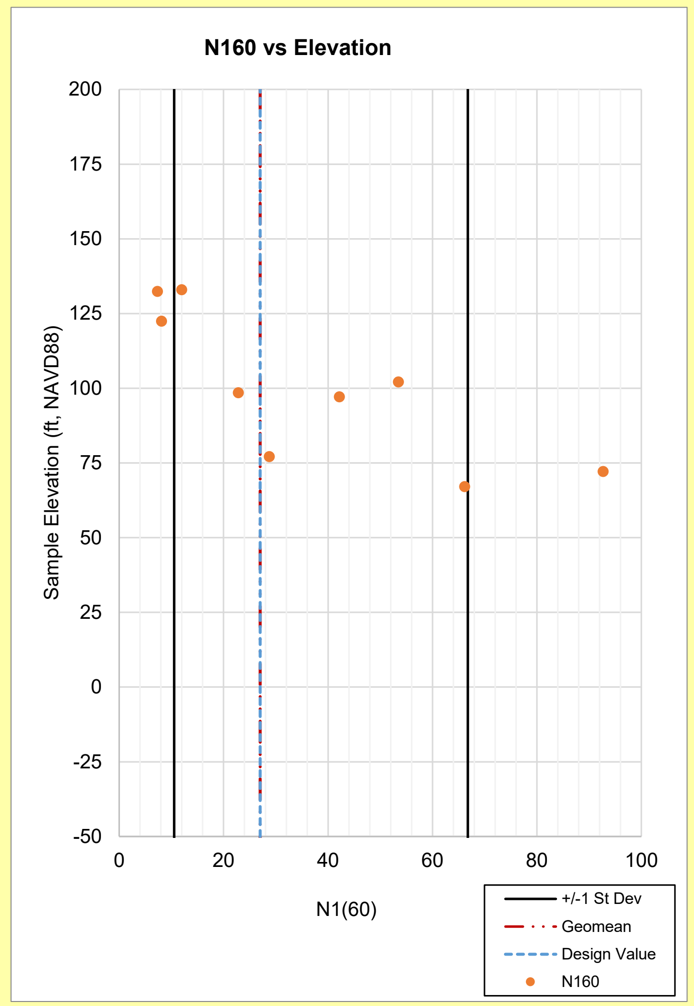
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	4	44%
MH	-	-
CL	-	-
CH	-	-
OL	5	56%
OH	-	-
Total	9	

Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	-	-
Little	-	-
Some	-	-
With	-	-
Numerous or Abundant	4	44%
Organic Soils (OL or OH)	5	56%
Total	9	

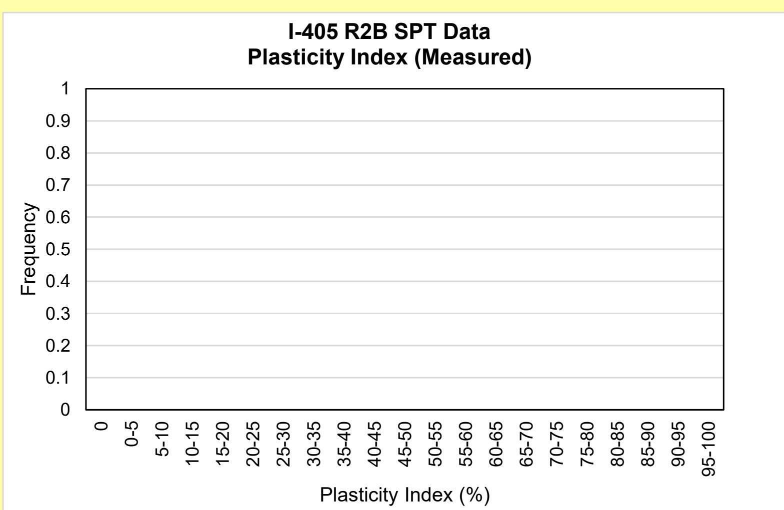
NOTES: If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha





NOTE: Standard deviations calculated assuming log normal distribution.



Design Property	Selection Method(s) / Assumption(s)
N60	Geomean due to log normal distribution.
N160	Geomean due to log normal distribution.
Unit Weight	Average of the minimum and maximum values for organic clays and silts in Figure 3 of the SPM.
Effective Friction Angle	Assume normally consolidated. Samples are generally low plasticity based on visual classification and index testing.
Fully Softened Friction Angle	Not applicable to organic soils.
Residual Friction Angle	Not applicable to organic soils.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion not applicable assuming normally consolidated soils.
Plasticity Index	No lab values. Soils are generally low plasticity so assume similar to ESU 4B.2.

Soil unit ID	3A	Loose granular (N160<=10)
Total Samples	31	

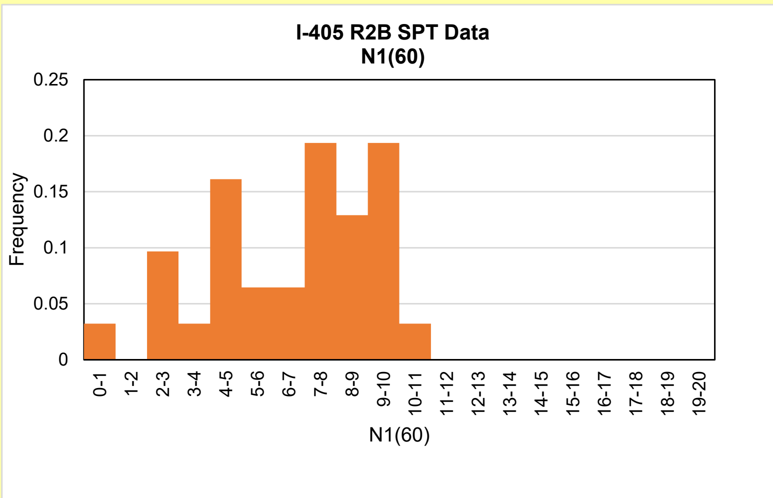
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	0	0	0	0	19	58	16	18	33	15
Max	9	9	10	10	19	58	41	26	50	24
Average	6	6	7	7	19	58	28	22	42	20
Geomean	5	5	6	6						19
StDev	2	2	3	3						6
15th Percentile	3	3	3	3						#NUM!
85th Percentile										#NUM!
COV	0.41	0.41	0.39	0.39						0.33
Count	31	31	31	31	1	1	6	2	2	2
Design Value		**6**		**7**			**28**			

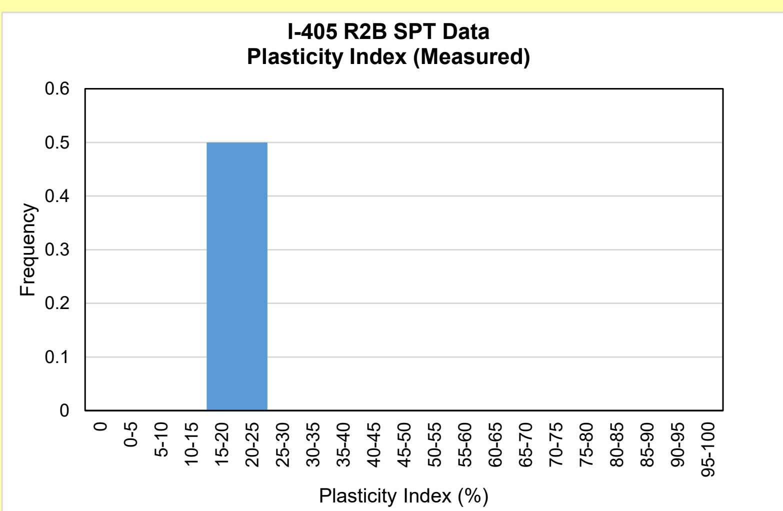
Sample Classification	Count	Percentage
GP	1	3%
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	1	3%
SP-SM	3	10%
SW	-	-
SW-SM	-	-
SM	19	61%
SC-SM	2	6%
SC	5	16%
ML	-	-
MH	-	-
CL	-	-
CH	-	-
OL	-	-
OH	-	-
Total	**31**	

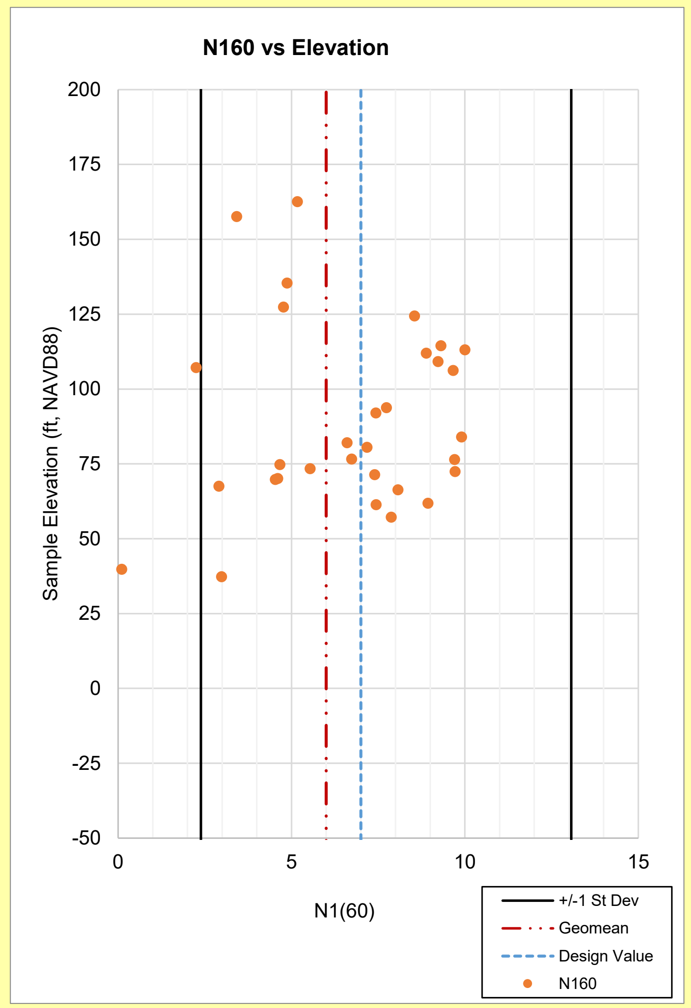
Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	5	16%
Little	-	-
Some	3	10%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**8**	

NOTES: If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Average due to non-standard and non-log normal distribution.
N160	Average due to non-standard and non-log normal distribution.
Unit Weight	Majority of samples are silty sand and sand with silt. Use lower end correlation to account for high fines content. Calculation re
Effective Friction Angle	Value determined using high end trend from Figure 7 of the SPM and linearly reducing approximately 1 degree for every 5% o
Fully Softened Friction Angle	Not applicable to coarse grained soils.
Residual Friction Angle	Not applicable to coarse grained soils.
Drilled Shafts Friction Angle	See correlation, no reduction to design value.
Effective Cohesion	Not applicable to coarse grained soils.
Plasticity Index	Not applicable to coarse grained soils.

Soil unit ID	3B	Med dense granular (10<N160<=30)

Total Samples 165

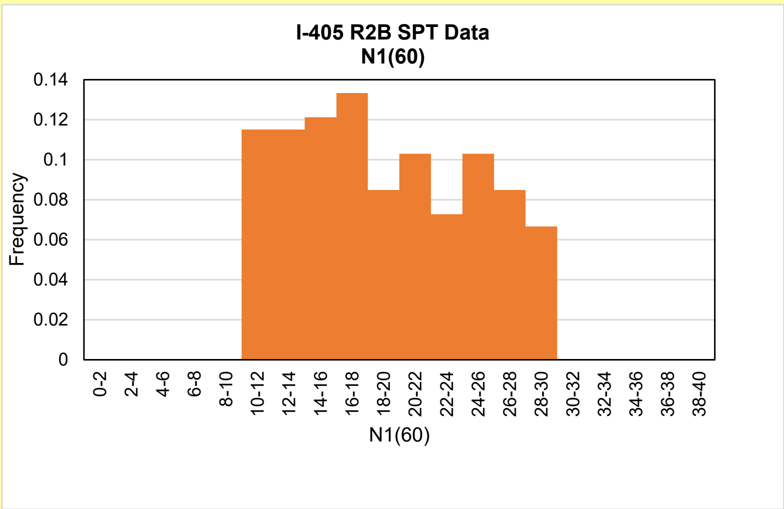
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	9	9	10	10	0	35	0	17	22	5
Max	33	33	30	30	48	94	48	27	54	27
Average	17	17	19	19	15	69	20	20	34	14
Geomean	16	16	18	18						12
StDev	6	6	6	6						9
15th Percentile	10	10	13	13						#NUM!
85th Percentile										#NUM!
COV	0.34	0.34	0.29	0.29						0.63
Count	165	165	165	165	18	18	48	5	5	5
Design Value		17		19			20			

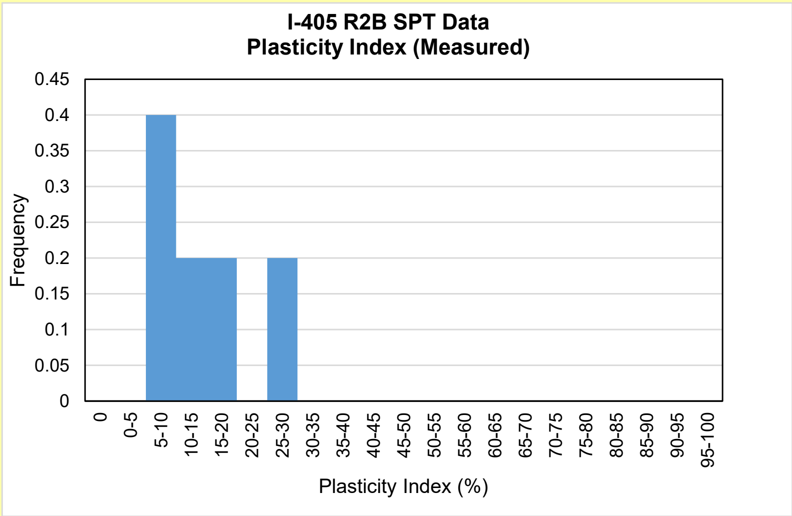
Sample Classification	Count	Percentage
GP	1	1%
GP-GM	6	4%
GW	6	4%
GW-GM	1	1%
GM	2	1%
GC	-	-
SP	9	5%
SP-SM	49	30%
SW	1	1%
SW-SM	3	2%
SM	78	47%
SC-SM	2	1%
SC	7	4%
ML	-	-
MH	-	-
CL	-	-
CH	-	-
OL	-	-
OH	-	-
Total	165	

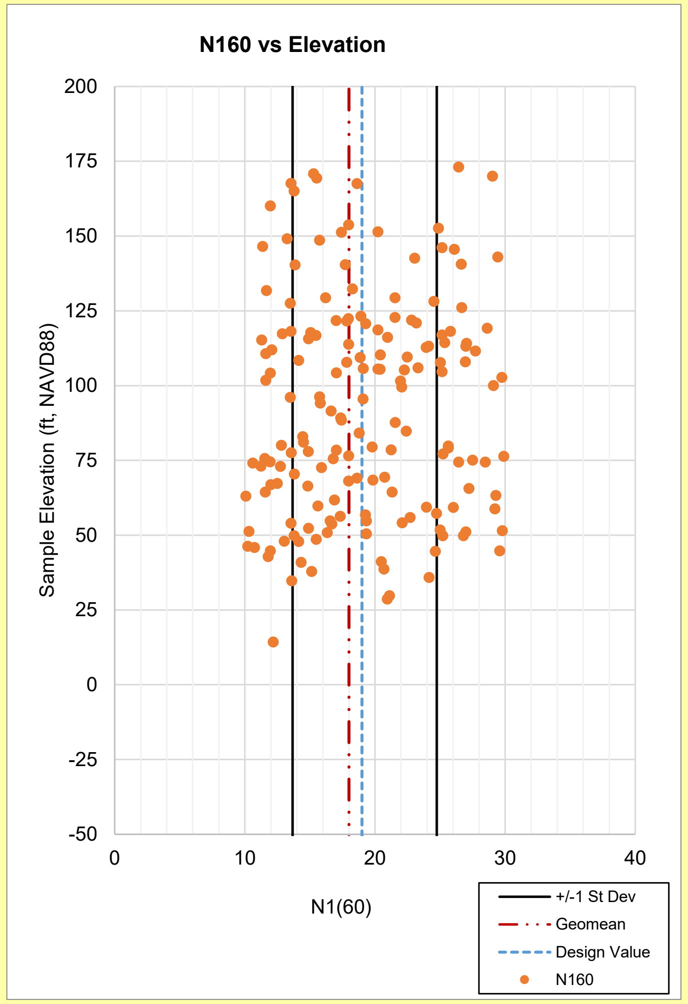
Organic Content Descriptor	Count	Percentage
Trace	4	2%
Few or Scattered	15	9%
Little	-	-
Some	9	5%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	28	

NOTES: If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Average due to standard distribution.
N160	Average due to standard distribution.
Unit Weight	Majority of samples are silty sand and sand with silt. Use lower end correlation to account for high fines content.
Effective Friction Angle	Value determined using high end trend from Figure 7 of the SPM and linearly reducing approximately 1 degree for every 5% o
Fully Softened Friction Angle	Not applicable to coarse grained soils.
Residual Friction Angle	Not applicable to coarse grained soils.
Drilled Shafts Friction Angle	See correlation, no reduction to design value.
Effective Cohesion	Not applicable to coarse grained soils.
Plasticity Index	Not applicable to coarse grained soils.

Soil unit ID	3C	Dense granular (30<N160<50)

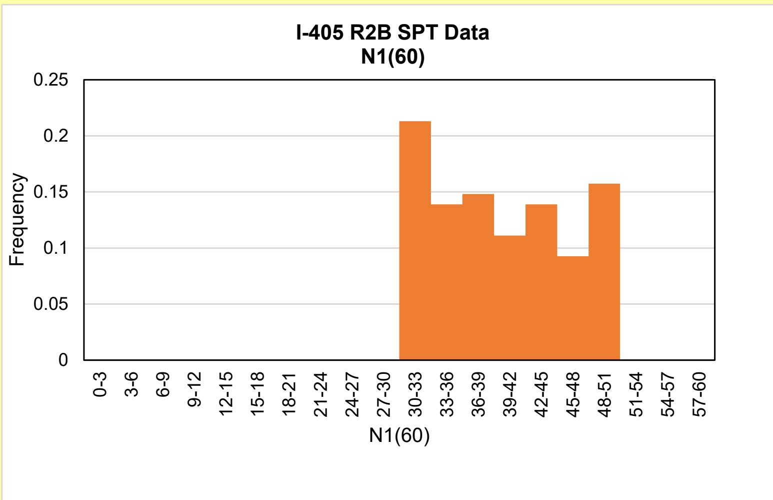
Total Samples 108

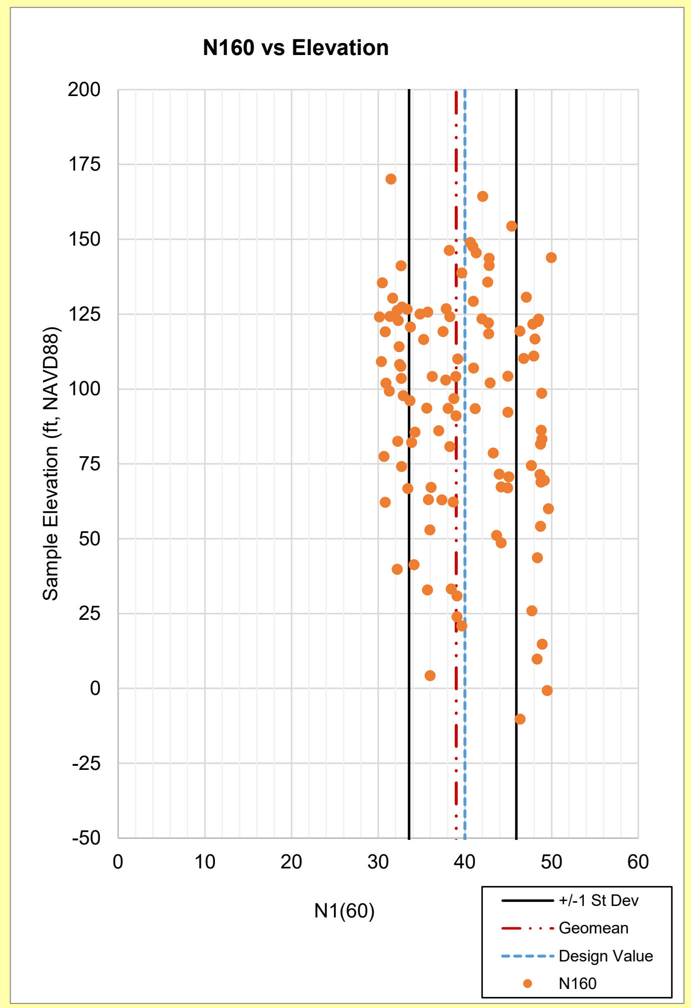
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	20	20	30	30	0	36	4	0	0	0
Max	80	80	50	50	54	91	47	0	0	0
Average	36	36	40	40	12	74	18	#DIV/0!	#DIV/0!	#DIV/0!
Geomean	35	35	39	39						#NUM!
StDev	12	12	6	6						#DIV/0!
15th Percentile	27	27	32	32						#NUM!
85th Percentile										#NUM!
COV	0.32	0.32	0.16	0.16						#DIV/0!
Count	108	108	108	108	13	16	29	0	0	0
Design Value		**36**		**40**			**18**			

Sample Classification	Count	Percentage
GP	3	3%
GP-GM	8	7%
GW	-	-
GW-GM	-	-
GM	1	1%
GC	-	-
SP	7	6%
SP-SM	23	21%
SW	3	3%
SW-SM	1	1%
SM	59	55%
SC-SM	1	1%
SC	2	2%
ML	-	-
MH	-	-
CL	-	-
CH	-	-
OL	-	-
OH	-	-
Total	**108**	

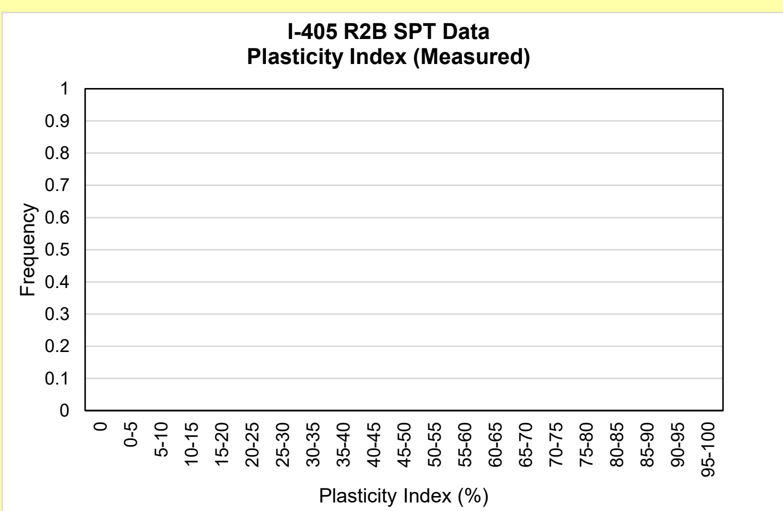
Organic Content Descriptor	Count	Percentage
Trace	1	1%
Few or Scattered	8	7%
Little	-	-
Some	-	-
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**9**	

NOTES:
If a sample has both organics and disturbance, that s
If a sample has both organics and noted as slide debris, tha





NOTE: Standard deviations calculated assuming log normal distribution.



Design Property	Selection Method(s) / Assumption(s)
N60	Average due to standard distribution.
N160	Average due to standard distribution.
Unit Weight	Majority of samples are silty sand and sand with silt, but dense to very dense. Use average trend to account for high fines c
Effective Friction Angle	Value determined using high end trend from Figure 7 of the SPM and linearly reducing approximately 1 degree for every 5% o
Fully Softened Friction Angle	Not applicable to coarse grained soils.
Residual Friction Angle	Not applicable to coarse grained soils.
Drilled Shafts Friction Angle	See correlation, no reduction to design value.
Effective Cohesion	Not applicable to coarse grained soils.
Plasticity Index	Not applicable to coarse grained soils.

Soil unit ID	3D	Very dense granular (N160>=50)

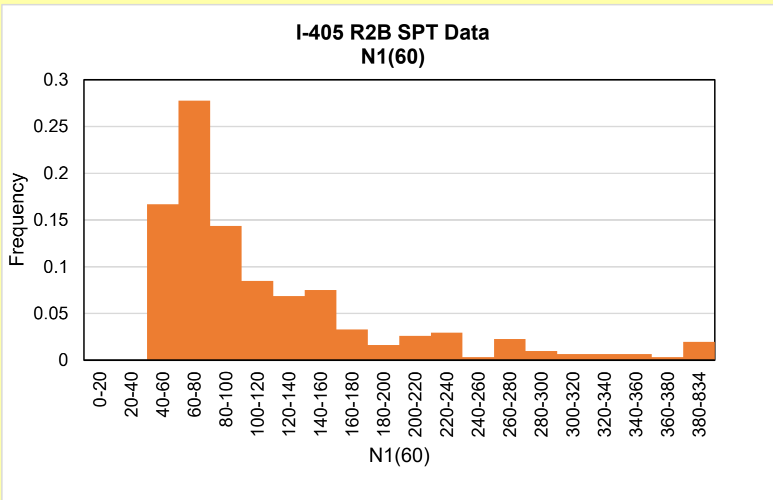
Total Samples 315

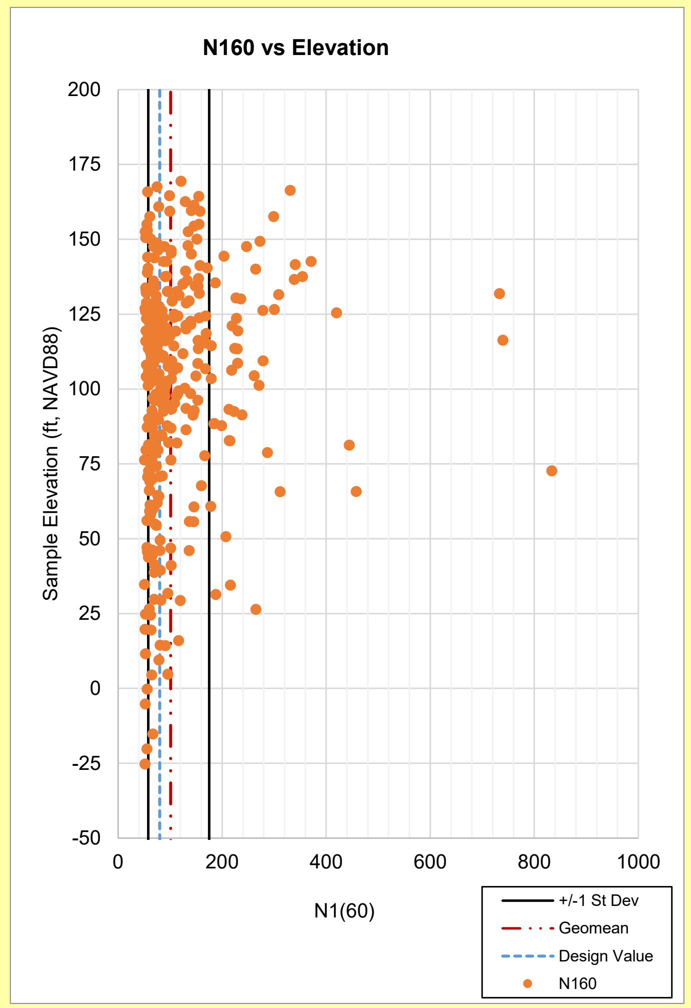
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	34	34	50	50	0	38	4	15	17	2
Max	968	100	834	100	52	92	50	28	41	21
Average	126	83	121	82	15	72	13	21	28	11
Geomean	102	80	101	80						8
StDev	104	21	98	18						8
15th Percentile	55	55	59	59						#NUM!
85th Percentile										#NUM!
COV	0.83	0.25	0.81	0.22						0.76
Count	306	306	306	306	31	31	65	4	6	4
Design Value		**80**		**80**			**13**			

Sample Classification	Count	Percentage
GP	4	1%
GP-GM	20	6%
GW	17	5%
GW-GM	6	2%
GM	9	3%
GC	1	0%
SP	26	8%
SP-SM	77	24%
SW	8	3%
SW-SM	23	7%
SM	118	37%
SC-SM	-	-
SC	6	2%
ML	-	-
MH	-	-
CL	-	-
CH	-	-
OL	-	-
OH	-	-
Total	**315**	

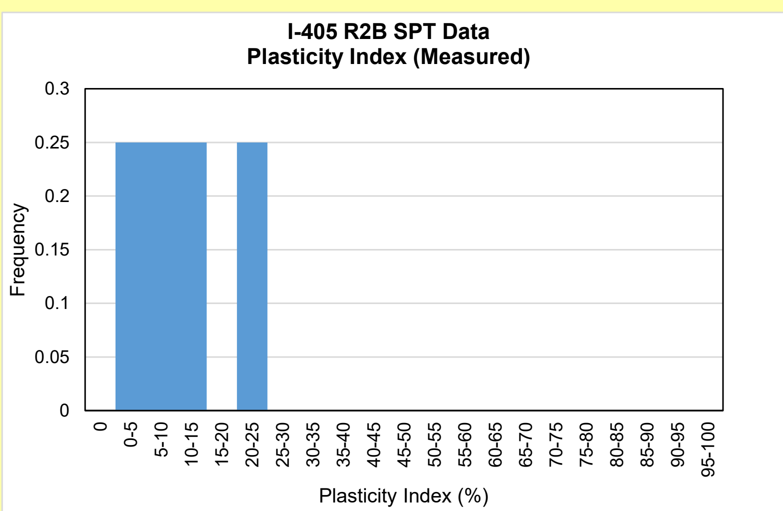
Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	5	2%
Little	-	-
Some	1	0%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**6**	

NOTES:
If a sample has both organics and disturbance, that
s
If a sample has both organics and noted as slide debris,
tha





NOTE: Standard deviations calculated assuming log normal distribution.



Design Property	Selection Method(s) / Assumption(s)
N60	Geomean due to log normal distribution.
N160	Geomean due to log normal distribution.
Unit Weight	Majority of samples are silty sand and sand with silt. Use average trend to account for high fines content but glacially o
Effective Friction Angle	Value determined using high end trend from Figure 7 of the SPM and linearly reducing approximately 1 degree for every 5% o
Fully Softened Friction Angle	Not applicable to coarse grained soils.
Residual Friction Angle	Not applicable to coarse grained soils.
Drilled Shafts Friction Angle	See correlation, no reduction to design value.
Effective Cohesion	Not applicable to coarse grained soils.
Plasticity Index	Not applicable to coarse grained soils.

Soil unit ID	4A	Soft to medium stiff fines (N160<=8)

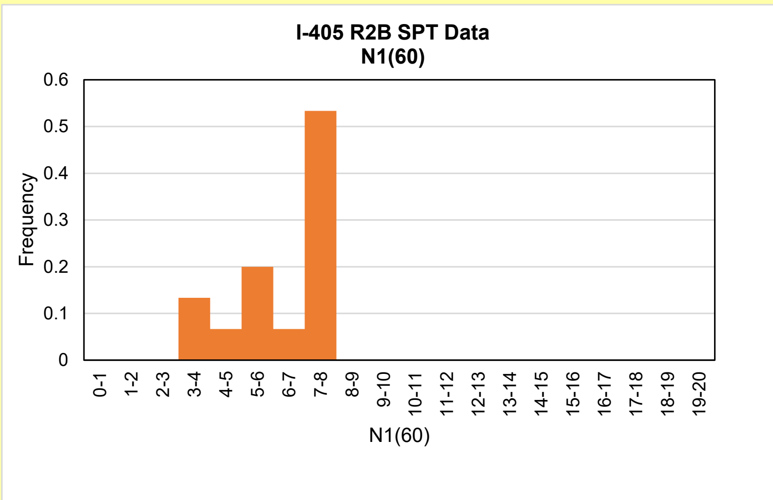
Total Samples 15

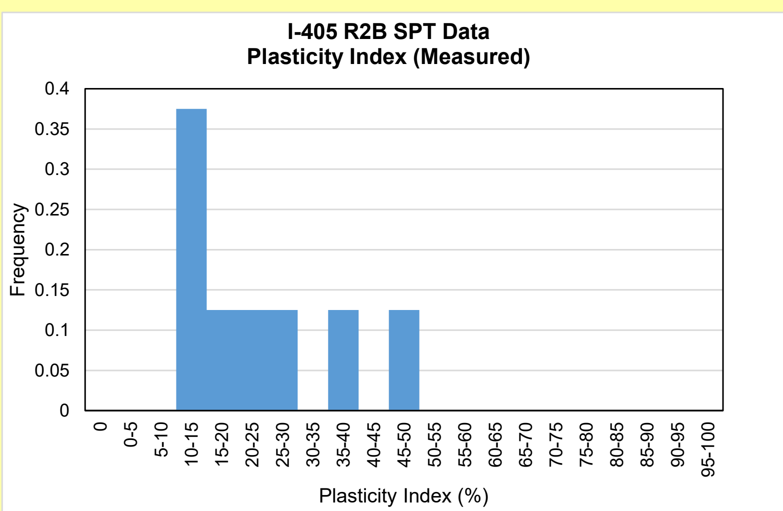
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	3	3	3	3	0	1	64	16	28	10
Max	9	9	8	8	0	1	99	37	75	45
Average	6	6	6	6	0	1	81	26	49	23
Geomean	5	5	6	6						20
StDev	2	2	2	2						12
15th Percentile	4	4	4	4						11
85th Percentile										#NUM!
COV	0.28	0.28	0.25	0.25						0.54
Count	15	15	15	15	1	1	7	8	8	8
Design Value		6		6			81			20

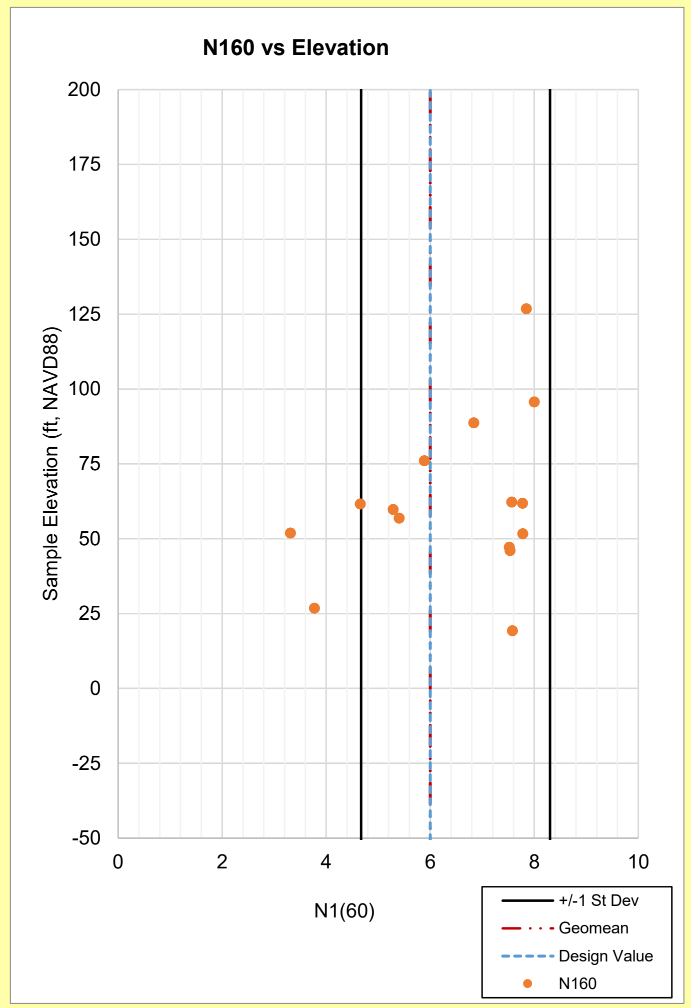
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	4	27%
MH	1	7%
CL	6	40%
CH	4	27%
OL	-	-
OH	-	-
Total	15	

Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	3	20%
Little	-	-
Some	1	7%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	4	

NOTES:
If a sample has both organics and disturbance, that s
If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Average due to non-standard and non-log normal distribution.
N160	Average due to non-standard and non-log normal distribution.
Unit Weight	Use lower trend due to soft to medium stiff (low density) fines.
Effective Friction Angle	Use normally consolidated correlation because OCR generally < 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Not applicable to ESU 4A.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Not applicable to normally consolidated soils per Sorenson correlation.
Plasticity Index	Lab testing geomean due to log normal distribution.

Soil unit ID	4B.1	Medium stiff to stiff fines (high plasticity - MH,CH) (8<N160<=15)

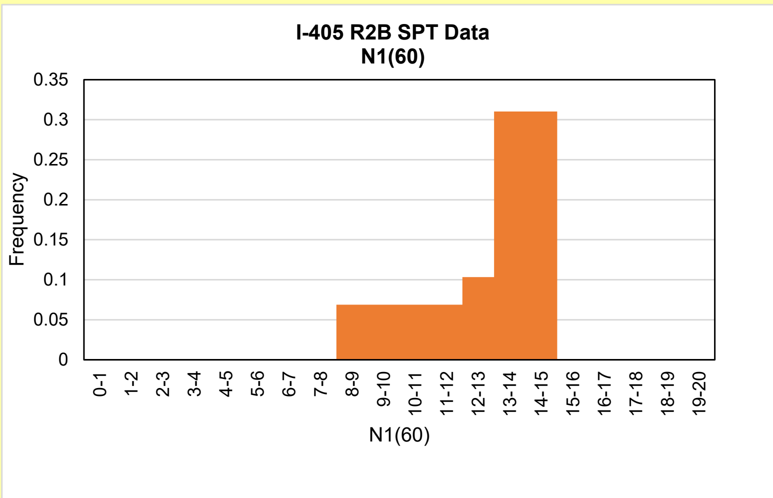
Total Samples 29

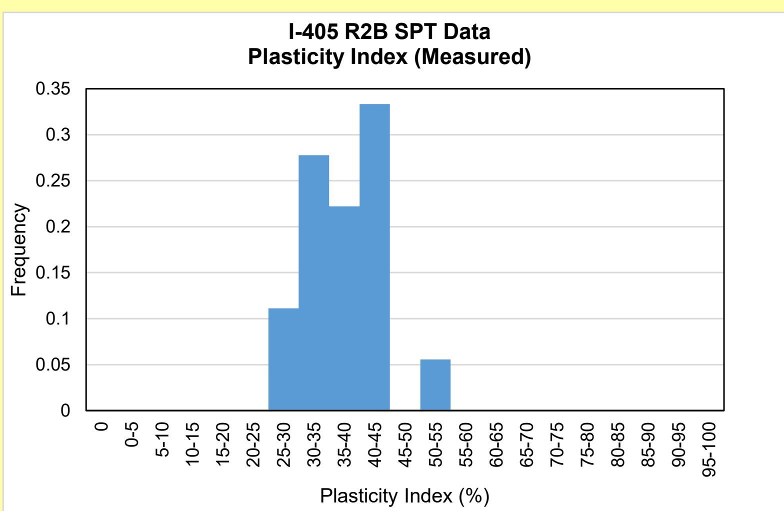
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	7	7	8	8	0	0	70	25	55	25
Max	26	26	15	15	1	13	100	41	95	54
Average	15	15	13	13	0	3	94	30	67	37
Geomean	14	14	13	13						36
StDev	5	5	2	2						7
15th Percentile	9	9	10	10						29
85th Percentile										45
COV	0.32	0.32	0.15	0.15						0.20
Count	29	29	29	29	7	7	8	18	18	18
Design Value		**15**		**13**			**94**			**37**

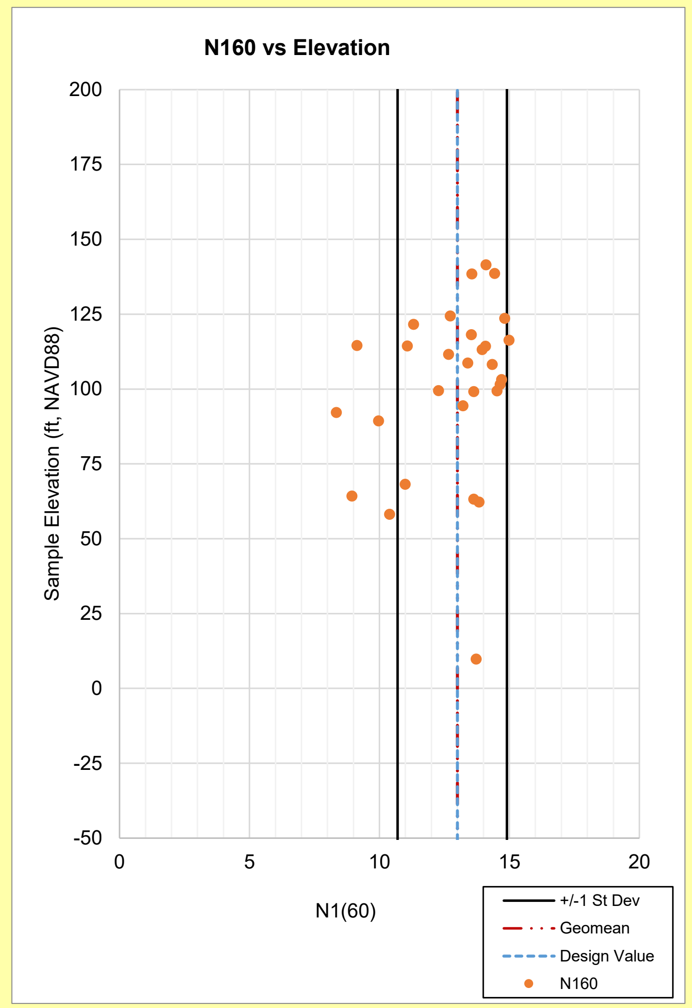
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	-	-
MH	8	28%
CL	-	-
CH	21	72%
OL	-	-
OH	-	-
Total	**29**	

Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	-	-
Little	-	-
Some	1	3%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**1**	

NOTES:
If a sample has both organics and disturbance, that s
If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Average due to non-standard and non-log normal distribution.
N160	Average due to non-standard and non-log normal distribution.
Unit Weight	Use lower trend due to medium stiff to stiff (lower density) fines.
Effective Friction Angle	Use normally consolidated correlation because OCR generally < 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Not applicable to ESU 4B.1.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Not applicable to normally consolidated soils per Sorenson correlation.
Plasticity Index	Lab testing average.

Soil unit ID	4B.2	Medium stiff to stiff fines (low plasticity - ML,CL) (8<N160<=15)

Total Samples 45

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	6	6	9	9	3	20	48	15	19	3
Max	29	29	15	15	16	37	92	29	49	32
Average	14	14	12	12	7	29	68	21	34	15
Geomean	12	12	12	12						13
StDev	6	6	2	2						7
15th Percentile	7	7	9	9						8
85th Percentile										23
COV	0.47	0.47	0.18	0.18						0.51
Count	45	45	45	45	4	4	6	18	18	18
Design Value		**14**		**12**			**68**			**15**

Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	18	40%
MH	-	-
CL	27	60%
CH	-	-
OL	-	-
OH	-	-
Total	**45**	

Organic Content Descriptor	Count	Percentage
Trace	2	4%
Few or Scattered	5	11%
Little	-	-
Some	4	9%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**11**	

NOTES:
If a sample has both organics and disturbance, that
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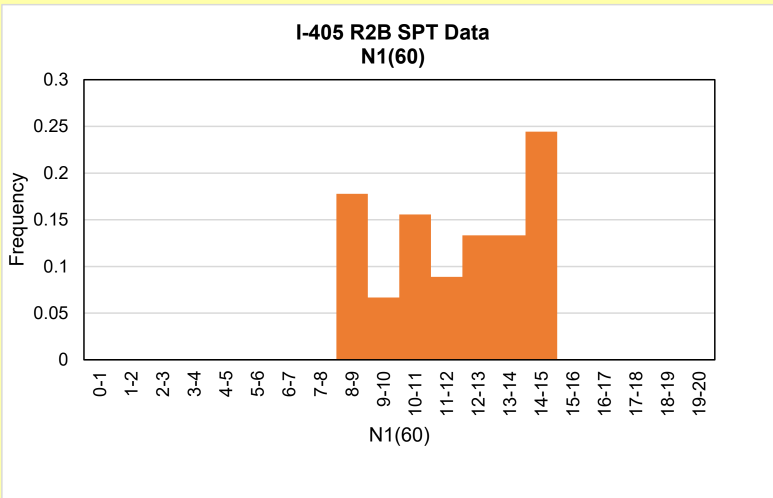
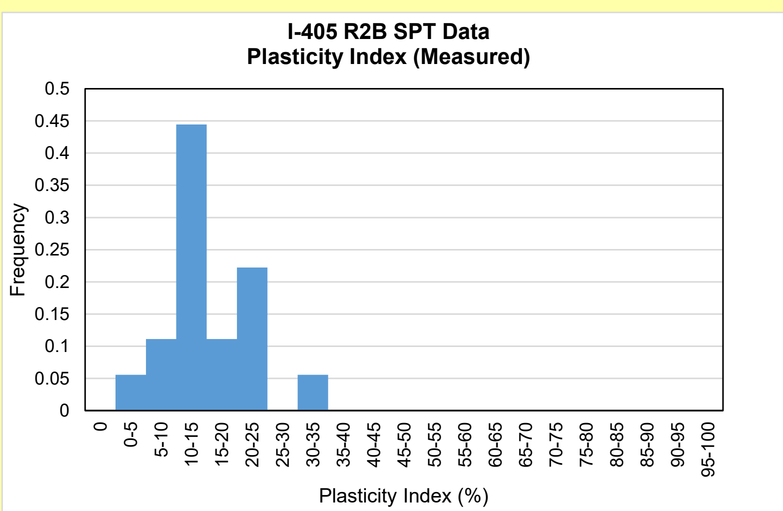
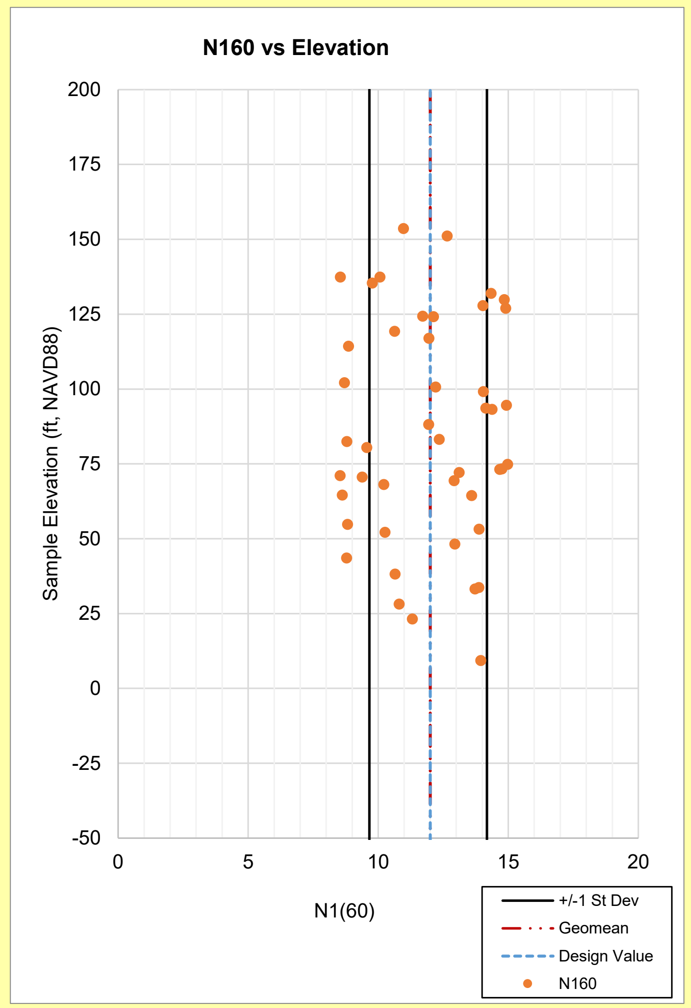






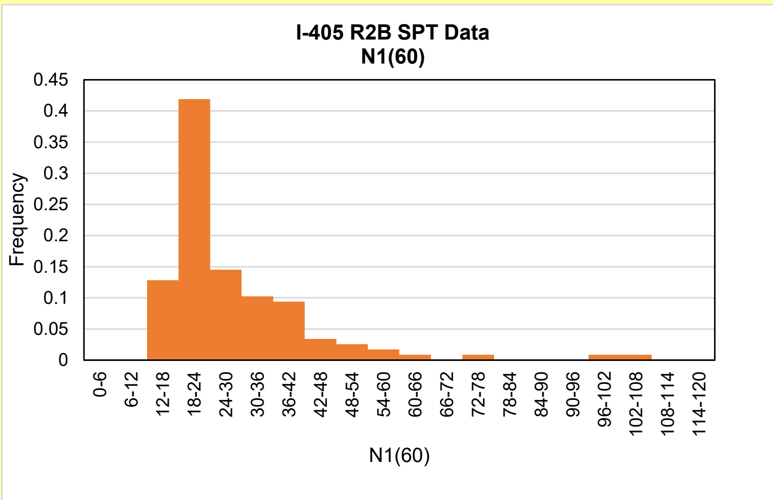
NOTE: Standard deviations calculated assuming log normal distribution.

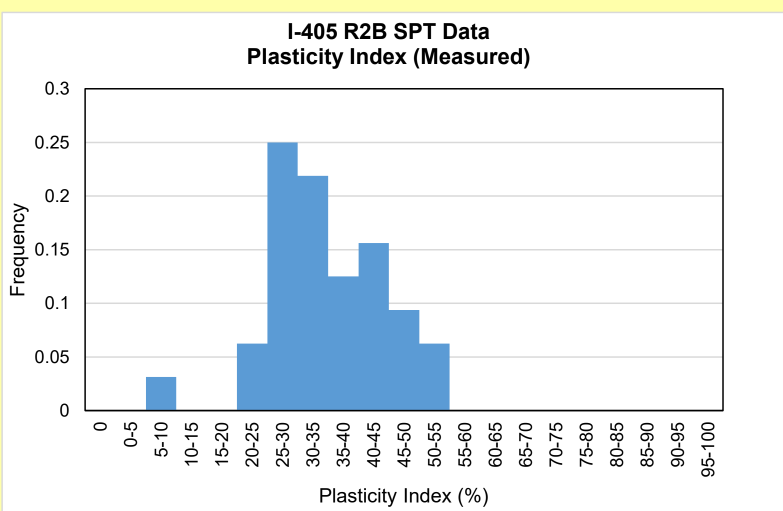
Design Property	Selection Method(s) / Assumption(s)
N60	Average due to standard distribution.
N160	Average due to standard distribution.
Unit Weight	Use lower trend due to medium stiff to stiff (lower density) fines.
Effective Friction Angle	Use normally consolidated correlation because OCR generally < 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Not applicable to ESU 4B.2.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Not applicable to normally consolidated soils per Sorenson correlation.
Plasticity Index	Lab testing average.

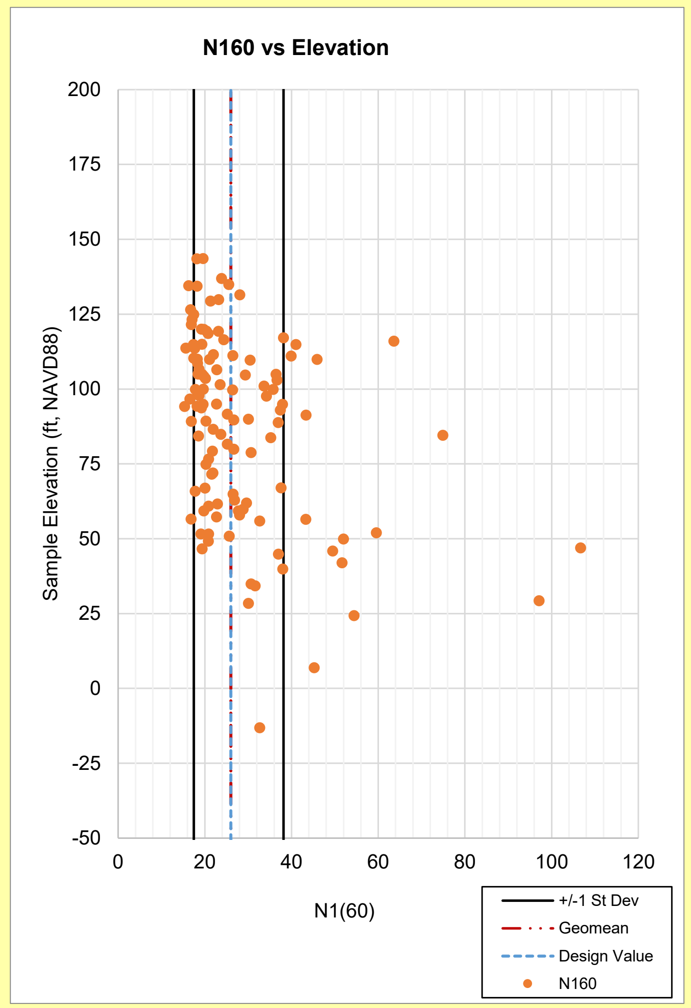
Soil unit ID	4C	Very stiff to hard fines - intact (high plasticity - MH,CH) (N160>15)

Total Samples 117

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	12	12	15	15	0	0	53	20	27	7
Max	144	100	107	100	0	0	100	56	84	53
Average	32	31	28	28	0	0	94	29	63	34
Geomean	28	28	26	26						32
StDev	20	17	15	14						10
15th Percentile	19	19	18	18						25
85th Percentile										42
COV	0.62	0.55	0.52	0.51						0.29
Count	117	117	117	117	7	7	8	32	32	32
Design Value		**28**		**26**			**94**			**34**







NOTE: Standard deviations calculated assuming log normal distribution.

Sample Classification	**Count**	**Percentage**
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	-	-
MH	26	22%
CL	-	-
CH	91	78%
OL	-	-
OH	-	-
Total	**117**	

Organic Content Descriptor	**Count**	**Percentage**
Trace	11	9%
Few or Scattered	2	2%
Little	-	-
Some	-	-
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**13**	

NOTES:

If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha

Design Property	Selection Method(s) / Assumption(s)
N60	Geomean due to log normal distribution.
N160	Geomean due to log normal distribution.
Unit Weight	Use average trend with maximum of 125 pcf due to hard fines but high plasticity.
Effective Friction Angle	Use over consolidated correlation because OCR generally > 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Not applicable to ESU 4C.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion included because OCR generally > 4.
Plasticity Index	Lab testing average.

Soil unit ID	4D	Very stiff to hard fines - intact (low plasticity - ML,CL) (N160>15)

Total Samples 436

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	13	13	15	15	0	0	15	14	18	2
Max	289	100	214	100	15	40	100	31	54	27
Average	42	40	38	37	2	16	79	23	35	13
Geomean	37	36	33	33						12
StDev	28	21	25	18						5
15th Percentile	21	21	21	21						8
85th Percentile										15
COV	0.66	0.51	0.66	0.50						0.40
Count	435	435	435	435	31	32	53	96	97	96
Design Value		**36**		**33**			**79**			**13**

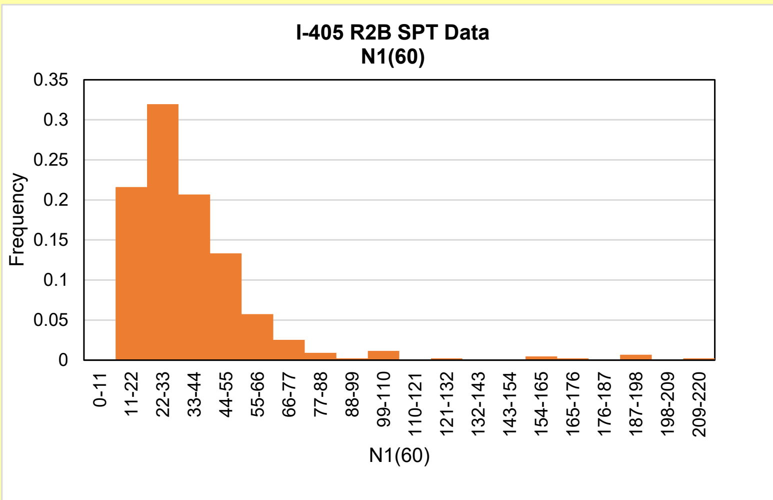
Sample Classification	**Count**	**Percentage**
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	155	36%
MH	-	-
CL	281	64%
CH	-	-
OL	-	-
OH	-	-
Total	**436**	

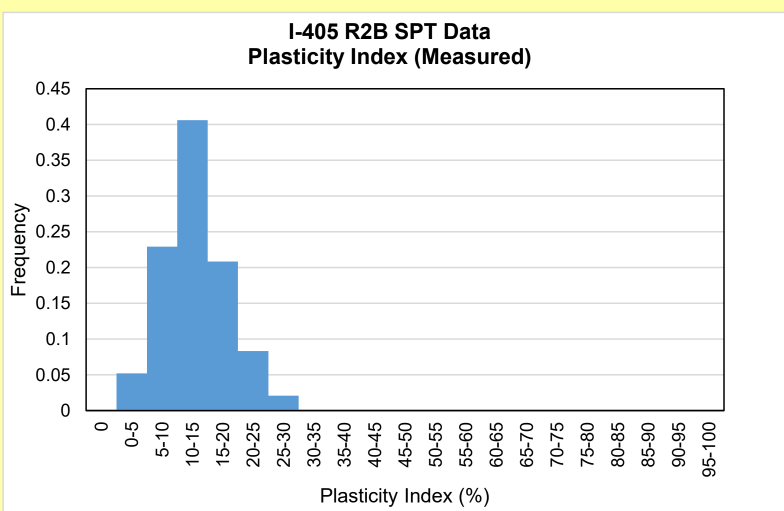
Organic Content Descriptor	**Count**	**Percentage**
Trace	2	0%
Few or Scattered	11	3%
Little	-	-
Some	4	1%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**17**	

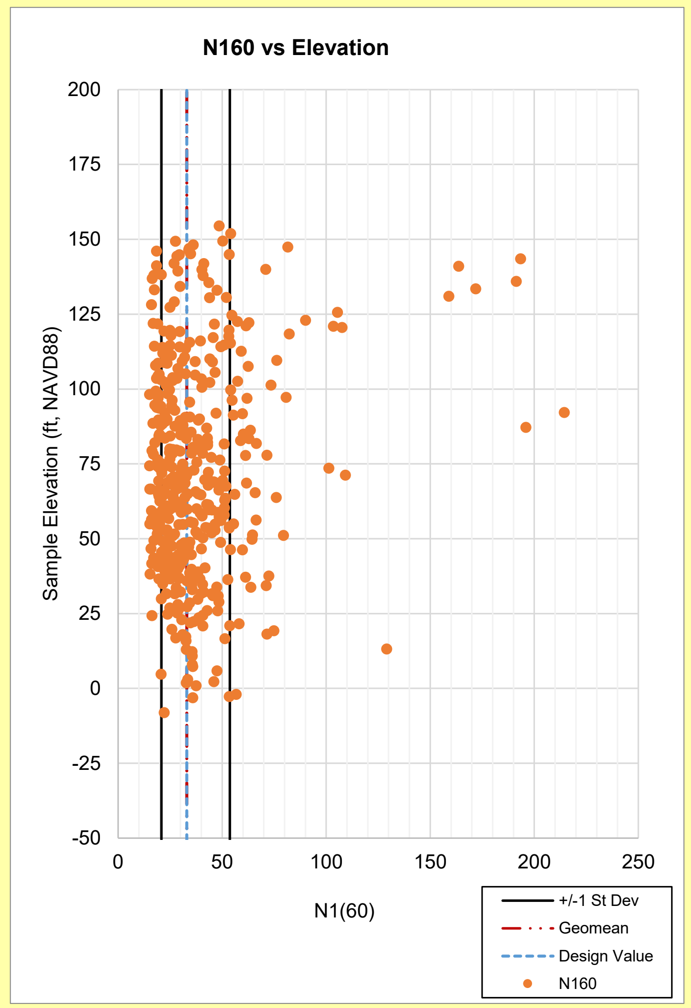
NOTES:

If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	**Selection Method(s) / Assumption(s)**
N60	Geomean due to log normal distribution.
N160	Geomean due to log normal distribution.
Unit Weight	Use average trend with maximum of 130 pcf due to hard fines but low plasticity.
Effective Friction Angle	Use over consolidated correlation because OCR generally > 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Not applicable to ESU 4D.
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion included because OCR generally > 4.
Plasticity Index	Lab testing average.

Soil unit ID	4E	Very stiff to hard fines - disturbed (high plasticity - MH,CH) (N160>15)

Total Samples 24

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	15	15	15	15	1	1	84	24	50	23
Max	50	50	65	65	1	15	100	32	84	53
Average	25	25	25	25	1	8	92	28	67	39
Geomean	23	23	24	24						37
StDev	11	11	10	10						12
15th Percentile	15	15	16	16						23
85th Percentile										#NUM!
COV	0.43	0.43	0.42	0.42						0.31
Count	24	24	24	24	1	2	2	6	6	6
Design Value		**25**		**25**			**92**			**39**

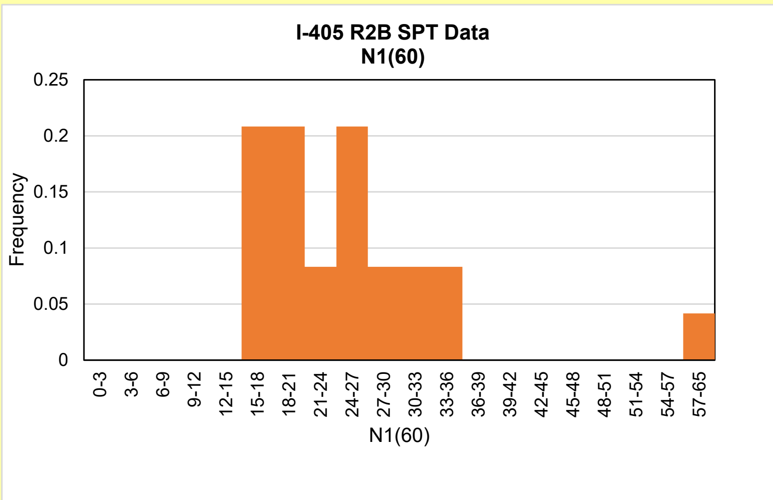
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	-	-
MH	3	13%
CL	-	-
CH	21	88%
OL	-	-
OH	-	-
Total	**24**	

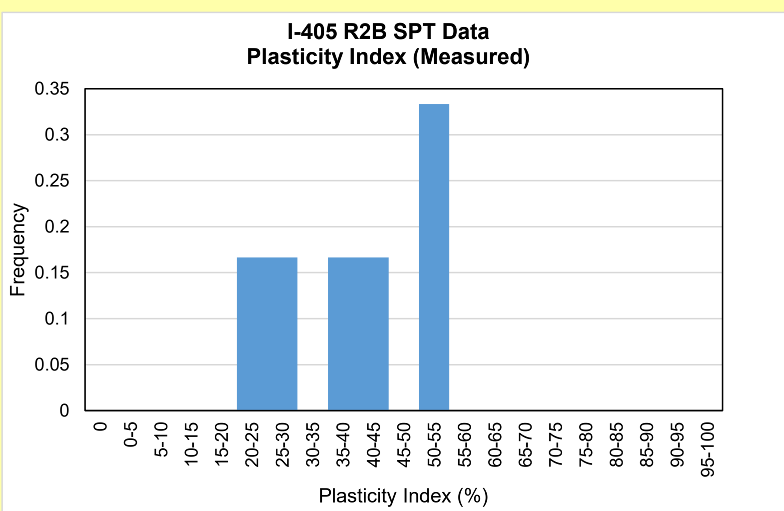
Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	-	-
Little	-	-
Some	-	-
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**0**	

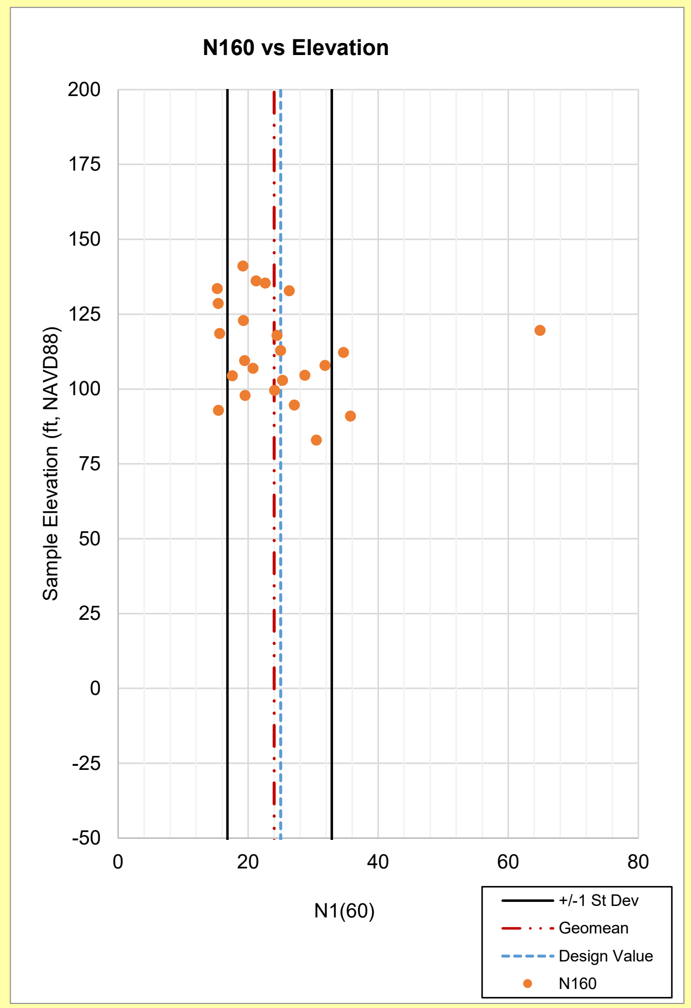
NOTES:

If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Average due to non-standard and non-log normal distribution.
N160	Average due to non-standard and non-log normal distribution.
Unit Weight	Use average trend with maximum of 125 pcf due to hard fines but high plasticity.
Effective Friction Angle	Residual friction angles only calculated for glacially overconsolidated fine-grained soils. Use OC correlation because OCR g
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion included because OCR generally > 4. Friction angle based on plasticity index.
Plasticity Index	Lab testing average.

Soil unit ID	4F	Very stiff to hard fines - disturbed (low plasticity - ML,CL) (N160>15)
Total Samples	55	

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	13	13	17	17	0	15	53	10	24	7
Max	143	100	172	100	5	30	85	28	49	29
Average	39	38	43	40	2	24	69	21	38	17
Geomean	34	34	36	35						15
StDev	24	21	31	24						7
15th Percentile	19	19	19	19						9
85th Percentile										#NUM!
COV	0.61	0.54	0.73	0.59						0.41
Count	55	55	55	55	4	4	11	21	21	21
Design Value		**34**		**35**			**69**			**17**

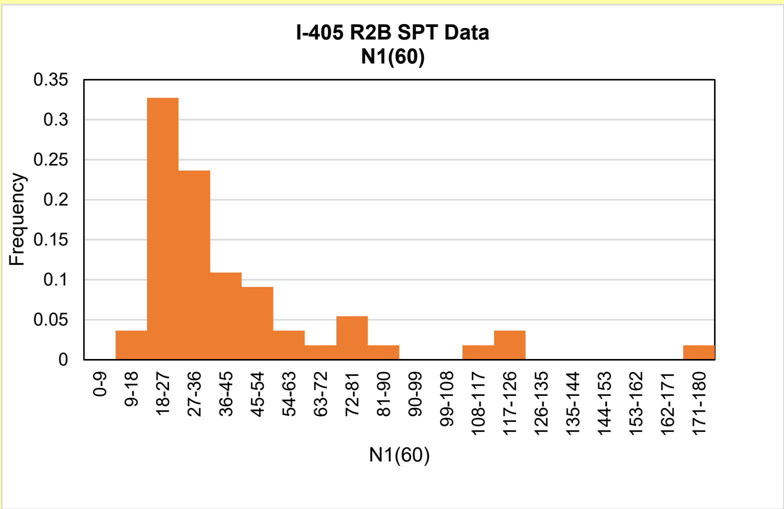
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	11	20%
MH	-	-
CL	44	80%
CH	-	-
OL	-	-
OH	-	-
Total	**55**	

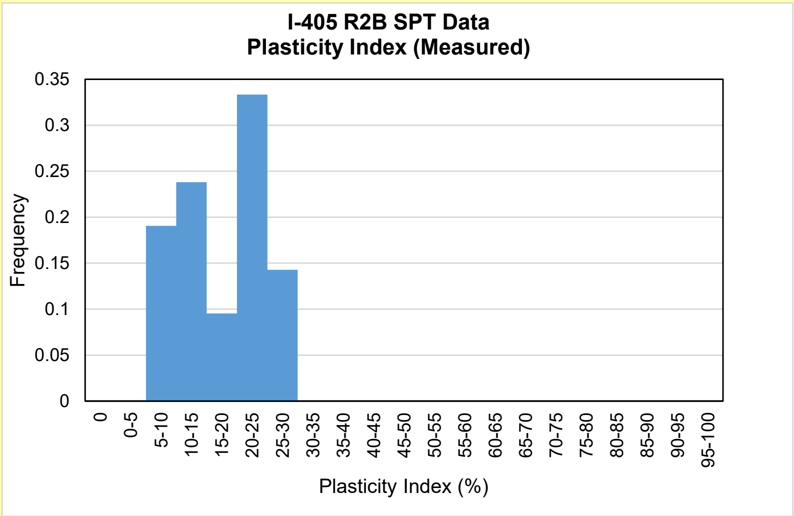
Organic Content Descriptor	Count	Percentage
Trace	-	-
Few or Scattered	3	5%
Little	-	-
Some	1	2%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	**4**	

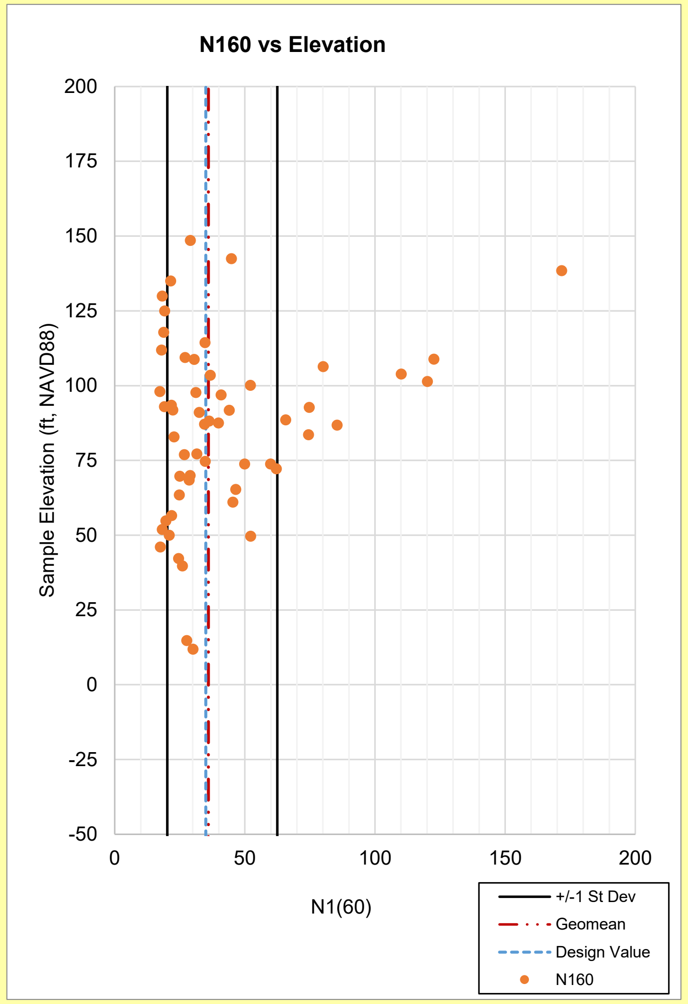
NOTES:

If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







NOTE: Standard deviations calculated assuming log normal distribution.

Design Property	Selection Method(s) / Assumption(s)
N60	Geomean due to log normal distribution.
N160	Geomean due to log normal distribution.
Unit Weight	Use average trend with maximum of 130 pcf due to hard fines but low plasticity.
Effective Friction Angle	Residual friction angles only calculated for glacially overconsolidated fine-grained soils. Use OC correlation because OCR g
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion included because OCR generally > 4. Friction angle based on plasticity index.
Plasticity Index	Lab testing average.

Figure D-13

Soil unit ID	5A	Landslide deposits - granular

Total Samples 8

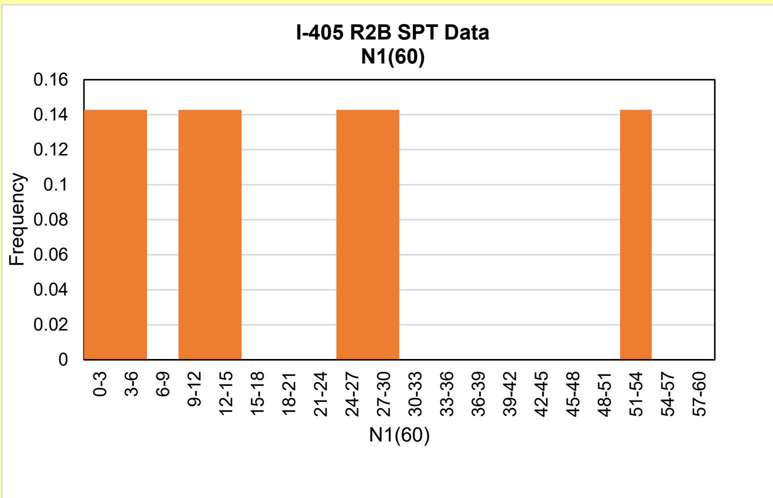
	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	0	0	0	0	0	0	0	0	0	0
Max	52	52	60	60	0	0	0	0	0	0
Average	21	21	25	25	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
Geomean	9	9	11	11						#NUM!
StDev	18	18	22	22						#DIV/0!
15th Percentile	1	1	2	2						#NUM!
85th Percentile										#NUM!
COV	0.86	0.86	0.89	0.89						#DIV/0!
Count	8	8	8	8	0	0	0	0	0	0
Design Value		9		11			30			

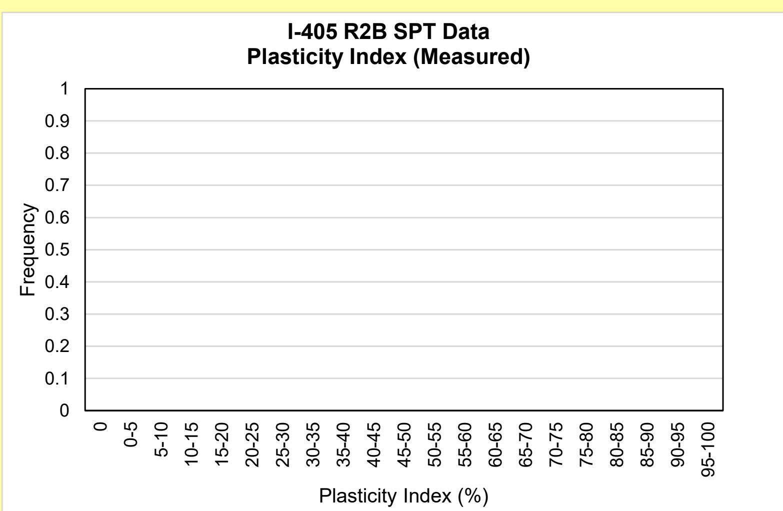
Sample Classification	Count	Percentage
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	8	100%
SC-SM	-	-
SC	-	-
ML	-	-
MH	-	-
CL	-	-
CH	-	-
OL	-	-
OH	-	-
Total	8	

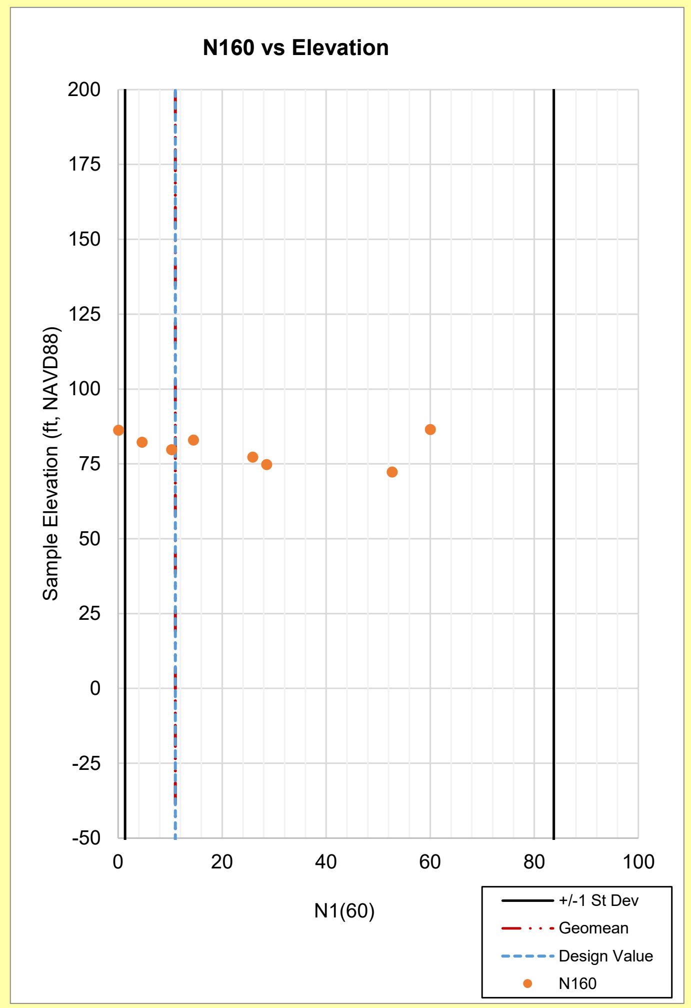
Organic Content Descriptor	Count	Percentage
Trace	2	25%
Few or Scattered	-	-
Little	-	-
Some	3	38%
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	-	-
Total	5	

NOTES: If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha







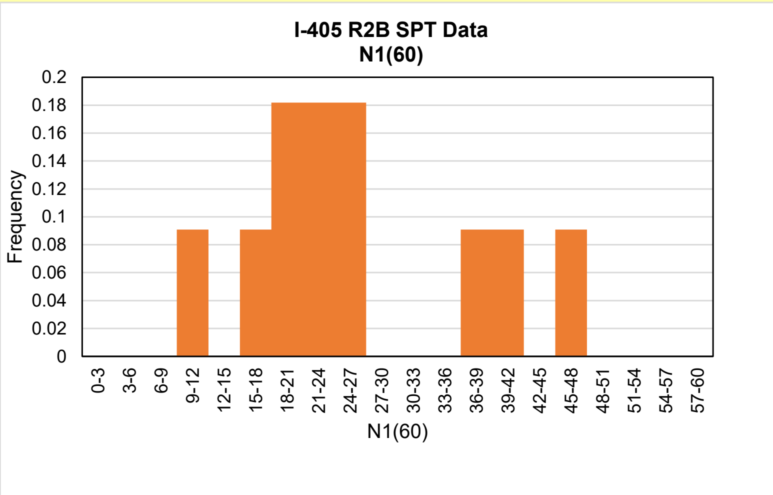
NOTE: Standard deviations calculated assuming log normal distribution.

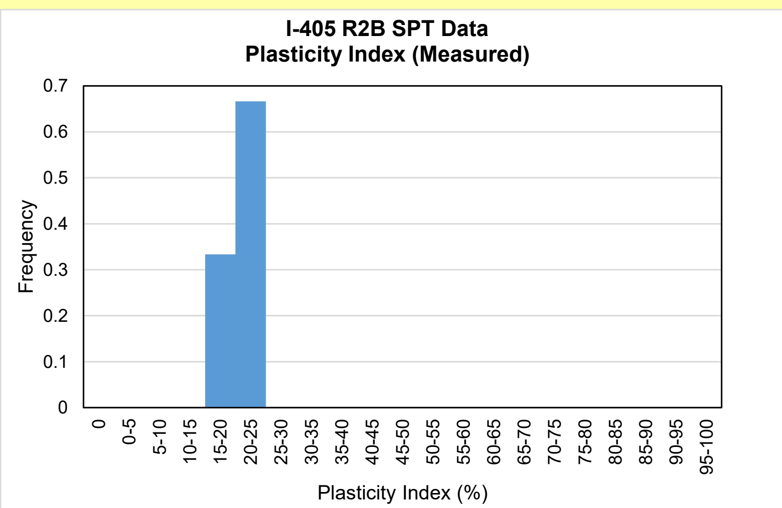
Design Property	Selection Method(s) / Assumption(s)
N60	Non-standard and non-log normal distribution, but use the geomean due to uncertainty in landslide units. Skews the value to
N160	Non-standard and non-log normal distribution, but use the geomean due to uncertainty in landslide units. Skews the value to
Unit Weight	All samples classified as silty sand. Use lower trend to account for high fines content.
Effective Friction Angle	Value determined using high end correlation from Figure 7 of the SPM and linearly reducing approximately 1 degree for e
Fully Softened Friction Angle	Not applicable to coarse grained soils.
Residual Friction Angle	Not applicable to coarse grained soils.
Drilled Shafts Friction Angle	See correlation, no reduction to design value.
Effective Cohesion	Not applicable to coarse grained soils.
Plasticity Index	Not applicable to coarse grained soils.

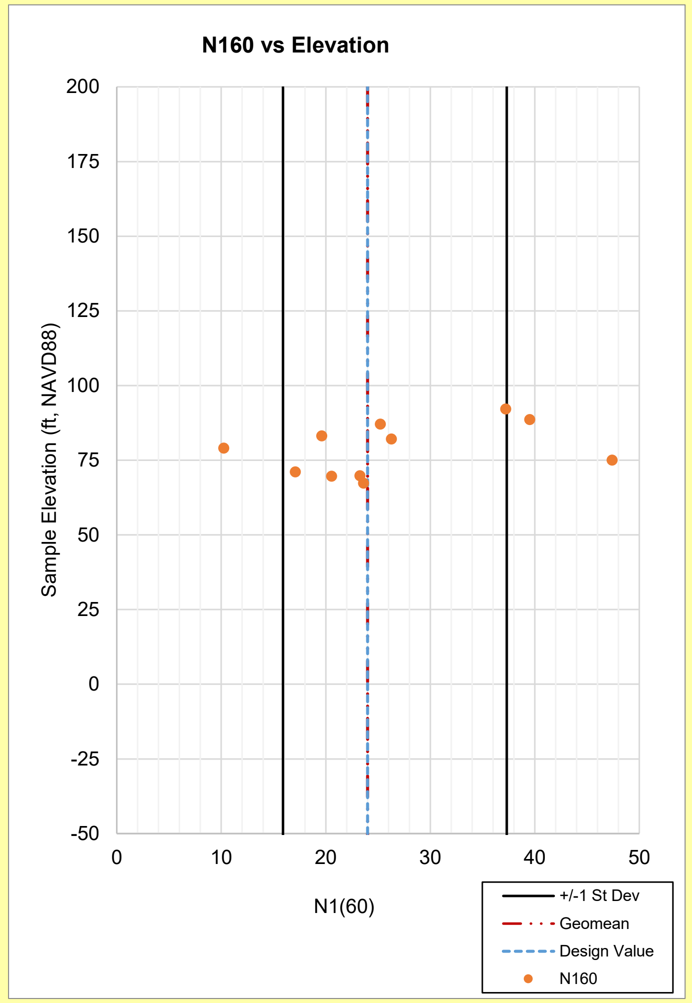
Soil unit ID	5B	Landslide deposits - fines

Total Samples 11

	N60	N60 LIMIT	N160	N160 LIMIT	% Gravel	% Sand	% Fines	PL	LL	PI
Min	9	9	10	10	0	0	0	15	34	15
Max	45	45	47	47	0	0	0	19	41	22
Average	24	24	26	26	#DIV/0!	#DIV/0!	#DIV/0!	18	37	19
Geomean	22	22	24	24						19
StDev	10	10	11	11						4
15th Percentile	13	13	16	16						#NUM!
85th Percentile										#NUM!
COV	0.42	0.42	0.41	0.41						0.19
Count	11	11	11	11	0	0	0	3	3	3
Design Value		22		24			82			19







NOTE: Standard deviations calculated assuming log normal distribution.

Sample Classification	**Count**	**Percentage**
GP	-	-
GP-GM	-	-
GW	-	-
GW-GM	-	-
GM	-	-
GC	-	-
SP	-	-
SP-SM	-	-
SW	-	-
SW-SM	-	-
SM	-	-
SC-SM	-	-
SC	-	-
ML	2	18%
MH	-	-
CL	3	27%
CH	1	9%
OL	5	45%
OH	-	-
Total	**11**	

Organic Content Descriptor	**Count**	**Percentage**
Trace	-	-
Few or Scattered	-	-
Little	2	18%
Some	-	-
With	-	-
Numerous or Abundant	-	-
Organic Soils (OL or OH)	5	45%
Total	**7**	

NOTES: If a sample has both organics and disturbance, that s

If a sample has both organics and noted as slide debris, tha

Design Property	**Selection Method(s) / Assumption(s)**
N60	Distribution is closer to a standard distribution, but use the geomean due to uncertainty in landslide units. Skews the value to
N160	Distribution is closer to a standard distribution, but use the geomean due to uncertainty in landslide units. Skews the value to
Unit Weight	Assume similar to ESU 4B.2. Use lower trend.
Effective Friction Angle	Use normally consolidated correlation because OCR generally < 4.
Fully Softened Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Residual Friction Angle	Calculated on a per sample basis (dependent on clay fraction, liquid limit, and vertical effective stress).
Drilled Shafts Friction Angle	Not applicable to fine-grained soils.
Effective Cohesion	Effective cohesion not applicable assuming normally consolidated soils.
Plasticity Index	Lab testing average.

In Association with

Appendix E
Calculations

In Association with

Contents

Appendix E-1
Seismic Hazard Calculations

In Association with

Appendix E-1.1
Seismic Hazard, Site Class & Wave Scattering Assessment

CALCULATION COVER SHEET

Project WSDOT I-405	**Structure/ Location/ Segment** Project Alignment	**Wood Project No.** PS19-203160.032100.0001

Title
Seismic Hazard

Computer Program (if used) Microsoft Excel, BridgeLink (SPECTRA)	**Version / Release No.**

Purpose and Objective
Evaluate seismic design parameters for Segments 1A to 2B for the project for all likely site classes and seismic performance objective levels of hazard.

Comments

Revision Log

Rev. No.	**Revision Description**
00	Initial submittal.

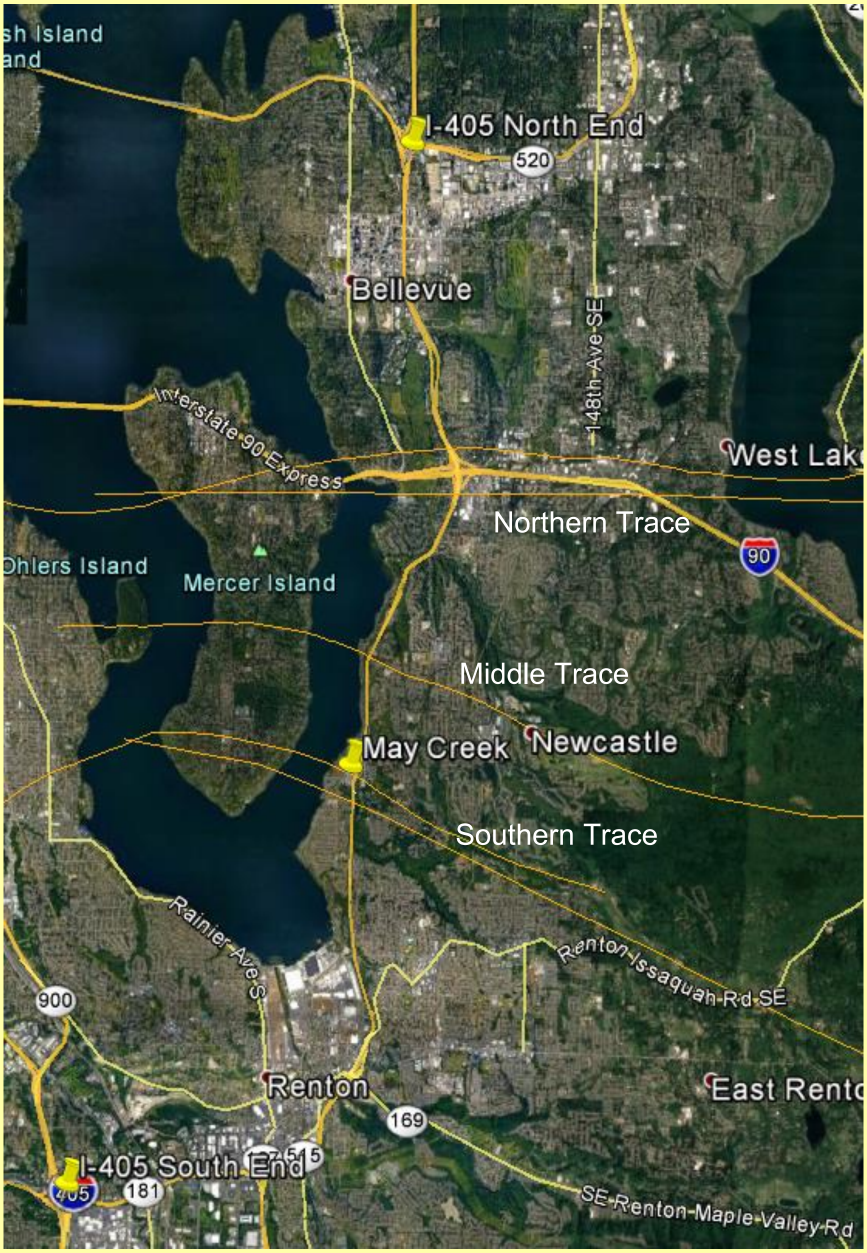
Sign Off

Rev. No.	**Originator (Print)** **Sign / Date**		**Reviewer (Print)** **Sign / Date**	
00	**Kevin Burlingham**		**James French**	
	K B	**3/30/2020**	James B French	**3/31/2020**

1.0 Background:

Wood is providing geotechnical engineering services for the I-405 improvements project. Below is an image of the alignment with the southern and northern ends marked and also the location of the bridge crossing at May Creek. Also shown are fault traces that cross the alignment for the Seattle fault (northern, middle, and southern traces).

Figure 1: Project Alignment with Fault Traces



The project is broken down into 5 segments (1A, 1B, 2A, 2B, and 2C). The geotechnical design for Segment 2C is being perfromed by Hart Crowser and so is not covered in this calculation. Below is a summary of the segments covered in this calculation.

Table 1: Project Segments Covered in this Calculation

Segment	Approximate Mile Range	Brief Description
1A	0-6.0	Southern end at intersection with I-5 up to Lake Washington near 24th St
1B	6.0-8.5	Southern end of Lake Washington near 24th St up to near 64th St
2A	8.5-10.0	Near 64th St up to where I-405 diverges from Lake Washington near 46th St
2B	10.0-12.0	Centered on intersection with I-90, from near 46th St up to near 22nd St

2.0 Problem:

Evaluate seismic design parameters for Segments 1A to 2B for the project for all likely site classes and seismic performance objective levels of hazard.

3.0 Approach:

The controlling specifications for the seismic design are the WSDOT Geotechnical Design Manual (GDM) Chapter 6 per Addendum 9 dated January 2019. Another specification is the WSDOT Bridge Design Manual (BDM) Chapter 4.

All structures are to be designed for a 7 percent probability of exceedance in 75 years seismic hazard, which is about a 1,034 year return period event (described in the GDM as an “approximate” return period of 1,000 yrs; this is similar to a 5% in 50 year probability of exceedance hazard, which has a 975 year return period as used by Caltrans). Essential or critical bridges should also be designed for the 30 percent probability of exceedance in 75 years seismic hazard, which has a year return period of about 210 years. The 1034 year return period event is designated as the Safety Evaluation Earthquake (SEE) and the 210 year return period event is designated as the Functional Evaluation Earthquake (FEE). These designations are from GDM Section 6-1.2.1.

For this project we are using the General Procedure method as outlined in GDM Section 6-2.1. This includes using specification/code based hazard (from GDM Section 6-3.1) with specification/code based ground motion response (from GDM Section 6-3.2.1).

To determine the seismic hazard for the SEE (1,000 yr RP) the ground motion tool called Spectra was used as recommended in Section 4.2.3.1 of the BDM. This tool uses the information published in the USGS National Seismic Hazards Mapping Project (USGS, 2014) as well as the updated site coefficients that are included in GDM Section 6-3.2.1.

For the FEE level of hazard (210 yr RP) we used the data from the USGS website at:

https://earthquake.usgs.gov/hazards/interactive

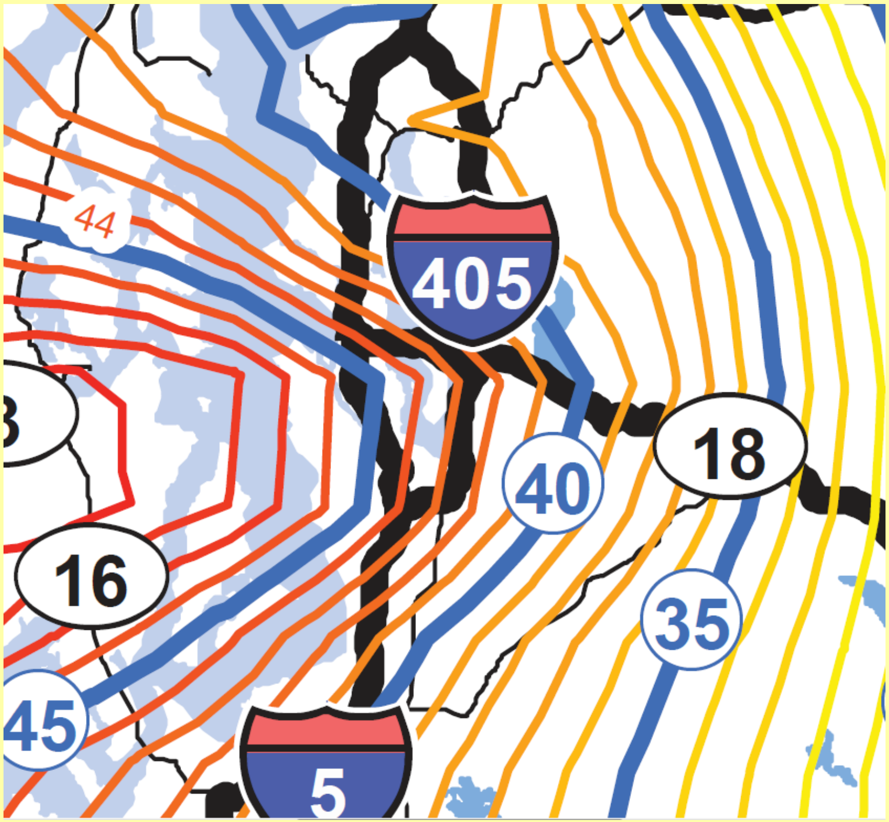
This is recommended in Section 6-3.1 of the GDM. The data was used to determine the spectral values for the site class B/C boundary at periods of PGA, 0.2 sec, and 1.0 sec for the 210 year return period. The site coefficients that are included in GDM Section 6-3.2.1 were then applied.

As recommended in GDM Section 6-1.3 the USGS website (https://earthquake.usgs.gov/hazards/interactive) was used to evaluate the magnitude-distance deaggregation at the periods of interest for the SEE and FEE seismic hazard levels.

4.0 Evaluations:

The first task was determining whether the seismic hazard should be evaluated for each segment, or if any segments needed to be divided into smaller portions based on the seismic hazard changing along the segment. The figures in Appendix 6-B of the GDM were reviewed in order to make this determination. Below is a portion of the figure for the peak horizontal acceleration (PHA) values. As shown the spectral acceleration values generally decrease going along the portion of I-405 from the intersection with I-5 to about the intersection with Highway 167 (portion that goes west-east) where the alignment turns to the north. The values are then relatively constant (i.e., the project route runs roughly along the contour lines, so the seismic accelerations are not expected to vary significantly along the segment) up to about the north end of the project at the intersection with I-90.

Figure 2: Portion of PHA Figure from Appendix 6-B of GDM



Based on the above figure (and the corresponding figures for the spectral accelerations at 0.2 and 1 second present a similar picture), it was determined that Segment 1A of the alignment should be divided into two areas. Area 1A-1 would go from the southwestern end of the alignment (at the intersection with I-5) over to the intersection with Highway 167 (i.e., the portion that goes east-west). Area 1A-2 would cover the remainder of Segment 1A (i.e., the portion that goes north-south). The other segments were not subdivided further as Segments 1B and 2A are along the contour lines and Segment 2B covers the area where the PHA values are changing in the northern area of the alignment. Below is a table summarizing these segment divisions along with the latitude and longitude values for their midpoints.

Table 2: Division of Project Segments for Evaluations

Segment	Midpoint Latitude	Midpoint Longitude	Approximate Mile Midpoint	Approximate Mile Range
1A-1	47.465145	-122.24191	1.2	0.0-2.3
1A-2	47.48641	-122.19447	4.1	2.3-6.0
1B	47.528242	-122.19771	7.3	6.0-8.5
2A	47.555697	-122.19083	9.3	8.5-10.0
2B	47.577447	-122.17425	11	10.0-12.0

The midpoint latitude and longitude were then copied into the Spectra program and the USGS website. For the USGS website the *Dynamic: Conterminous U.S. 2014 (update) (v4.2.0)* option was selected for the *Edition* option. The spectral acceleration values for the PGA, S_s (0.2 sec value), and the S_1 (1.0 sec value) for the B/C boundary site class were then taken from Spectra (to be used for the SEE) and the USGS website (to be used for the FEE).

These values were copied into a spreadsheet (Seismic Hazard I-405.xlsx) onto separate tabs (Summary 1A-1, Summary 1A-2, etc.) for each segment in columns C and D. The site coefficients from GDM Section 6-3.2.1 were then input into the spreadsheet tabs below the spectral acceleration values so that they could be used to calculate the site-class-dependent design values.

Columns E, G, I, and K of each tab then calculate the F_{PGA}, F_a, and F_v values to use for the FEE and SEE hazard levels for site classes of C and D. Linear interpolation is used for spectral values between the values given in the tables.

Site Class C and D were chosen for the evaluations as those site classes should cover the various geologic conditions along the alignment. This was based on a quick review of boring logs and available shear wave velocity data along the alignment. The site class for each structure should be determined at the time of design of that particular structure and the appropriate seismic parameters chosen for that site class. If additional site classes are required to cover the conditions along the alignment then this calculation should be revised.

Columns F, H, J, and L of each tab calculate the design spectral acceleration values by multiplying the B/C boundary values for PGA, 0.2 sec, and 1.0 sec by the corresponding F_{PGA}, F_a, and F_v values.

To evaluate the magnitudes to use in liquefaction evaluations along the alignment the USGS website was used. The values from the hazard at PGA were tabulated based on that being the dominant period for liquefaction hazard (typical equations for the cyclic stress ratio are based on PGA for liquefaction). The mean magnitudes are summarized below for the segments for which the data was tabulated. As shown the mean magnitude does not vary significantly along the alignment. Also tabulated below are the percent contribution to the hazard from the Cascadia Subduction zone sources per the USGS website. This is tabulated for use in determination of whether large magnitude events are a significant contributor to the seismic hazard at the site; this determination is used in evaluations for liquefaction lateral spreading. Plots for the deaggregations are also included for Segments 1A-1 and 2B to show that there is insignificant variation along the alignment.

Table 3: Deaggregation Values in Percent

Segment	Mean Magnitude, SEE	Mean Magnitude, FEE	Subduction Zone Contribution, SEE	Subduction Zone Contribution, FEE
1A-1	7.0	6.8	9.0	8.9
1B	7.0	6.8	8.7	8.7
2B	7.0	6.8	8.9	8.6

Figure 3: Deaggregation for Segment 1A-1, 1,000 year RP, PGA

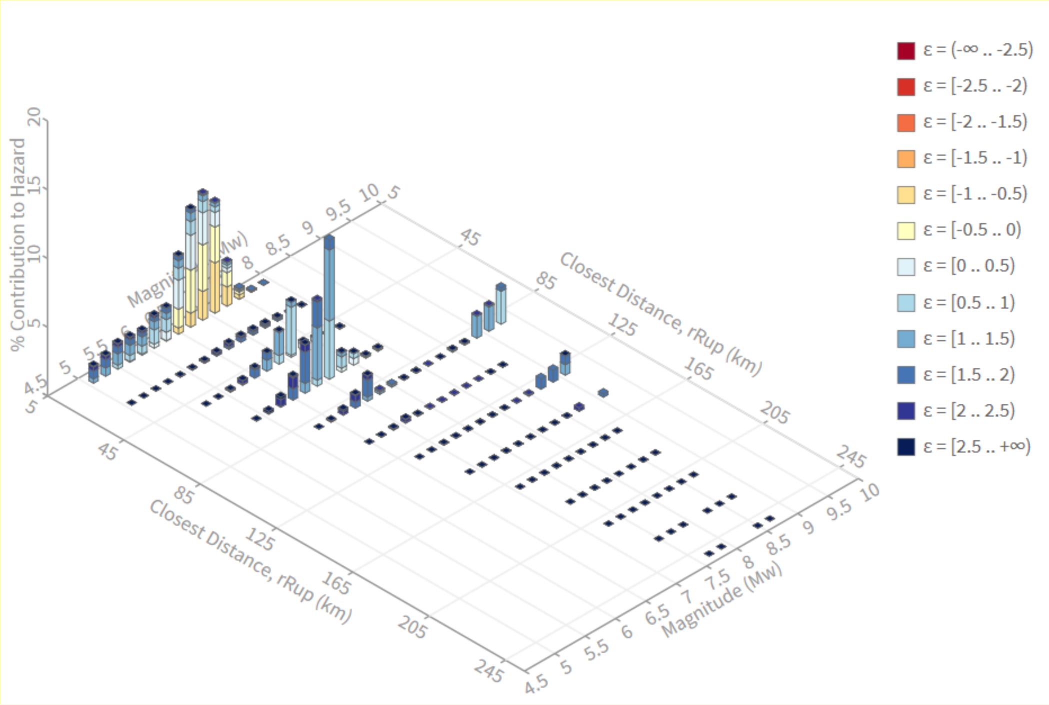


Figure 4: Deaggregation for Segment 1A-1, 210 year RP, PGA

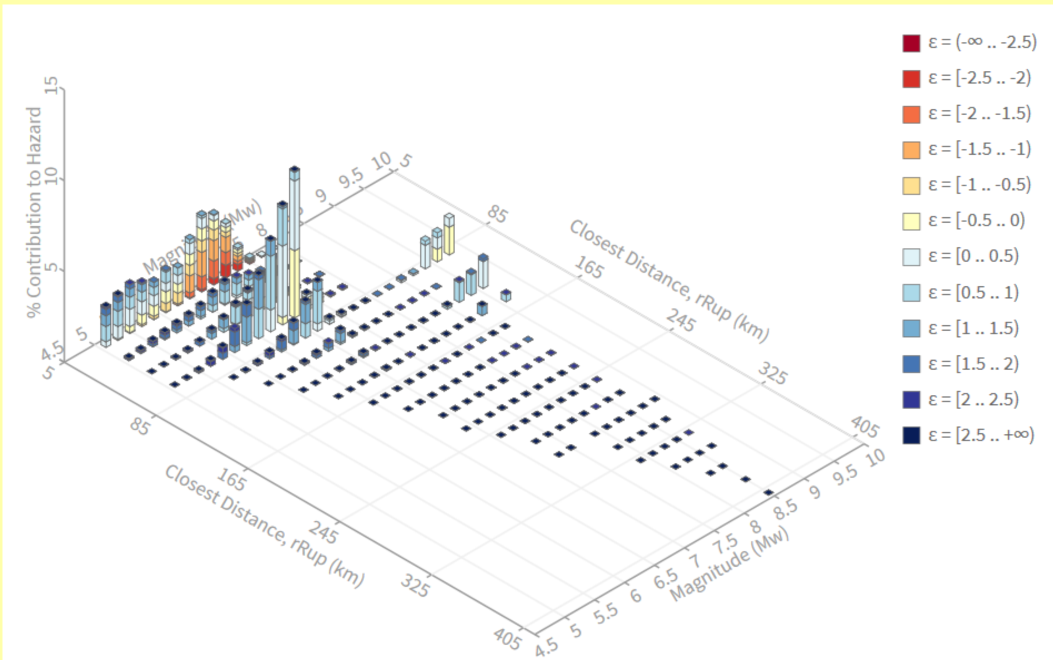


Figure 5: Deaggregation for Segment 2B, 1,000 year RP,PGA

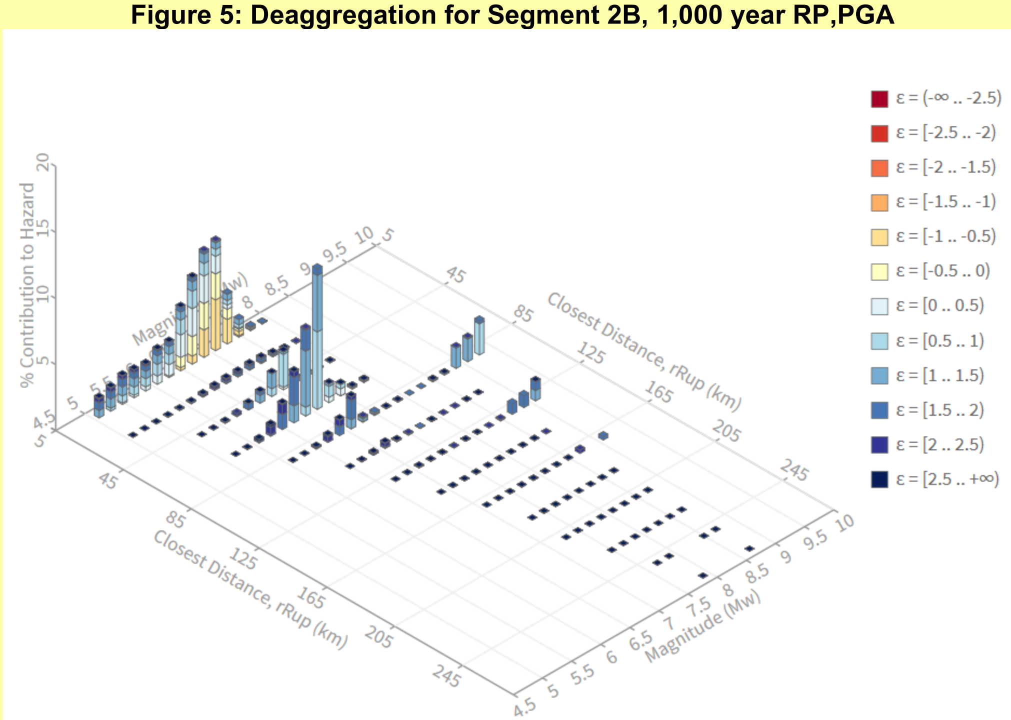
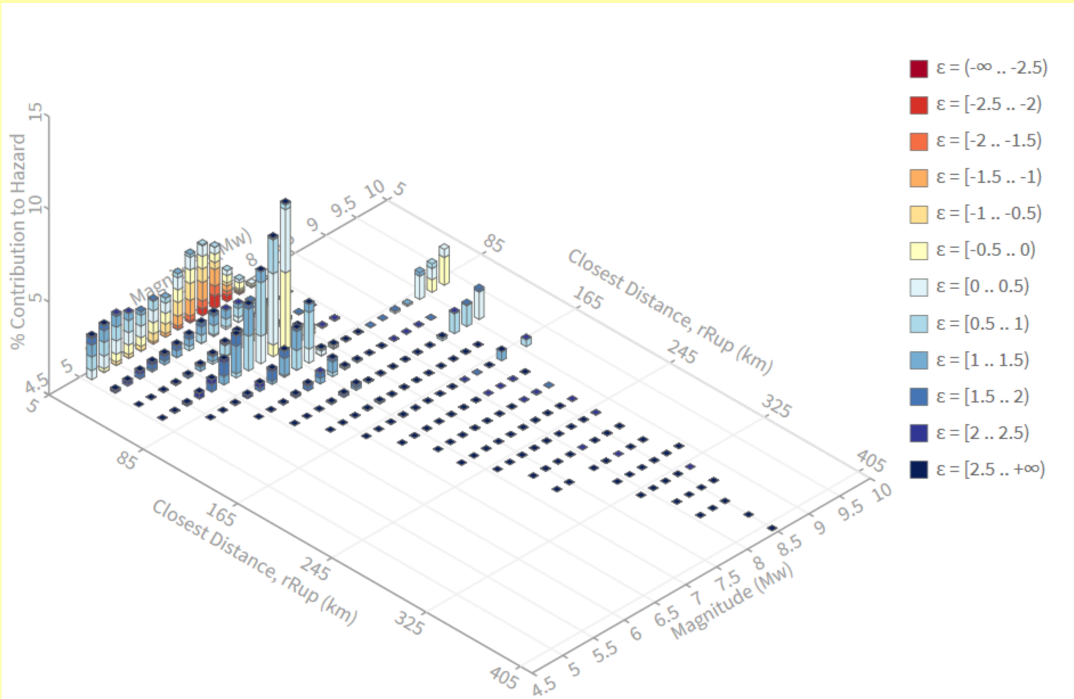


Figure 6: Deaggregation for Segment 2B, 210 year RP, PGA



5.0 Conclusions:

The following are the evaluated seismic parameters for the I-405 project segments as defined above.

Segment 1A-1 (MP 0.0 to 2.3, South End to Highway 167):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.438g	0.438g	0.207g	0.207g
F_{PGA}	1.162	1.200	1.393	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.509g	0.526g	0.288g	0.248g
Short-period (0.2 second) spectral acceleration (S_S)	1g	1g	0.467g	0.467g

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site coefficient (Fa)	1.100	1.200	1.427	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.1g	1.2g	0.666g	0.607g
1.0 second period spectral acceleration (S_1)	0.286g	0.286g	0.112g	0.112g
Site coefficient (Fv)	2.028	1.500	2.376	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.58g	0.429g	0.266g	0.168g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 1A-2 (MP 2.3 to 6.0, Highway 167 to near 24th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.43g	0.43g	0.202g	0.202g
F_{PGA}	1.170	1.200	1.398	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.503g	0.516g	0.282g	0.242g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.456g	0.456g
Site coefficient (Fa)	1.108	1.200	1.435	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.654g	0.592g
1.0 second period spectral acceleration (S_1)	0.28g	0.28g	0.11g	0.11g
Site coefficient (Fv)	2.040	1.500	2.380	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.571g	0.42g	0.262g	0.165g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

wood.

SHEET 9 OF 10
JOB NO. PS19203160
COMPUTED BY K. Burlingham
PROJECT I-405
DATE 3/30/2020
SUBJECT Seismic Hazard
CHECKED BY JF Date: 3/31/2020

Segment 1B (MP 6.0 to 8.5, near 24th St to near 64th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.434g	0.434g	0.202g	0.202g
F_{PGA}	1.166	1.200	1.398	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.506g	0.521g	0.282g	0.242g
Short-period (0.2 second) spectral acceleration (S_S)	0.988g	0.988g	0.455g	0.455g
Site coefficient (Fa)	1.105	1.200	1.436	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.092g	1.186g	0.654g	0.592g
1.0 second period spectral acceleration (S_1)	0.284g	0.284g	0.11g	0.11g
Site coefficient (Fv)	2.032	1.500	2.380	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.577g	0.426g	0.262g	0.165g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 2A (MP 8.5 to 10.0, near 64th St to near 46th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.431g	0.431g	0.2g	0.2g
F_{PGA}	1.169	1.200	1.400	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.504g	0.517g	0.28g	0.24g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.451g	0.451g
Site coefficient (Fa)	1.108	1.200	1.439	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.649g	0.587g
1.0 second period spectral acceleration (S_1)	0.283g	0.283g	0.109g	0.109g

Parameter	1,000 year RP SEE Value	1,000 year RP SEE Value	210 year RP FEE Value	210 year RP FEE Value
Site coefficient (Fv)	2.034	1.500	2.382	1.500
1.0 second design response acceleration $S_{D1} = S_1 \times Fv$	0.576g	0.425g	0.26g	0.164g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 2B (MP 10.0 to 12.0, near 46th St to near 22nd St):

Parameter	1,000 year RP SEE Value	1,000 year RP SEE Value	210 year RP FEE Value	210 year RP FEE Value
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.422g	0.422g	0.198g	0.198g
F_{PGA}	1.178	1.200	1.403	1.202
Site-Adjusted Peak Ground Acceleration (A_S)	0.497g	0.506g	0.278g	0.238g
Short-period (0.2 second) spectral acceleration (S_S)	0.959g	0.959g	0.447g	0.447g
Site coefficient (Fa)	1.116	1.200	1.442	1.300
Short Period design response acceleration (S_{DS}) = $S_S \times Fa$	1.071g	1.151g	0.645g	0.581g
1.0 second period spectral acceleration (S_1)	0.278g	0.278g	0.108g	0.108g
Site coefficient (Fv)	2.044	1.500	2.385	1.500
1.0 second design response acceleration $S_{D1} = S_1 \times Fv$	0.568g	0.417g	0.257g	0.162g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

6.0 Attachments:

No	Name of document	Tabs (if any)	Pages
1	Seismic Hazard I-405.xlsx	*Summary 1A-1, Summary 1A-2, Summary 1B, Summary 2A, Summary 2B*	-

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.207	0.438	1.393	0.288	1.162	0.509	1.200	0.248	1.200	0.526
6	Ss	0.2	0.467	1.000	1.427	0.666	1.100	1.100	1.300	0.607	1.200	1.200
7	S1	1	0.112	0.286	2.376	0.266	2.028	0.580	1.500	0.168	1.500	0.429

	A	B	C	D	E	F	G
12		Fpga					
13		PGA	PGA	PGA	PGA	PGA	PGA
14	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
15	A						
16	B						
17	C	1.3	1.2	1.2	1.2	1.2	1.2
18	D	1.6	1.4	1.3	1.2	1.1	1.1
19	E						

	A	B	C	D	E	F	G
21		Fa					
22		PGA	PGA	PGA	PGA	PGA	PGA
23	Site Class	0.25	0.5	0.75	1	1.25	1.5
24	A						
25	B						
26	C	1.3	1.3	1.2	1.2	1.2	1.2
27	D	1.6	1.4	1.2	1.1	1	1
28	E						

	A	B	C	D	E	F	G
30		Fv					
31		PGA	PGA	PGA	PGA	PGA	PGA
32	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
33	A						
34	B						
35	C	1.5	1.5	1.5	1.5	1.5	1.4
36	D	2.4	2.2	2	1.9	1.8	1.7
37	E						

M	N	O	P	Q
	975 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.438g	0.438g	0.207g	0.207g
F_{PGA}	1.162	1.200	1.393	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.509g	0.526g	0.288g	0.248g
Short-period (0.2 second) spectral acceleration (S_S)	1g	1g	0.467g	0.467g
Site coefficient (Fa)	1.100	1.200	1.427	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.1g	1.2g	0.666g	0.607g
1.0 second period spectral acceleration (S_1)	0.286g	0.286g	0.112g	0.112g
Site coefficient (Fv)	2.028	1.500	2.376	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.58g	0.429g	0.266g	0.168g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.202	0.43	1.398	0.282	1.170	0.503	1.200	0.242	1.200	0.516
6	Ss	0.2	0.456	0.98	1.435	0.654	1.108	1.086	1.300	0.592	1.200	1.176
7	S1	1	0.110	0.28	2.380	0.262	2.040	0.571	1.500	0.165	1.500	0.420

M	N	O	P	Q
	975 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.43g	0.43g	0.202g	0.202g
F_{PGA}	1.170	1.200	1.398	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.503g	0.516g	0.282g	0.242g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.456g	0.456g
Site coefficient (Fa)	1.108	1.200	1.435	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.654g	0.592g
1.0 second period spectral acceleration (S_1)	0.28g	0.28g	0.11g	0.11g
Site coefficient (Fv)	2.040	1.500	2.380	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.571g	0.42g	0.262g	0.165g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Fpga

	A	B	C	D	E	F	G
13		PGA	PGA	PGA	PGA	PGA	PGA
14	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
15	A						
16	B						
17	C	1.3	1.2	1.2	1.2	1.2	1.2
18	D	1.6	1.4	1.3	1.2	1.1	1.1
19	E						

Fa

	A	B	C	D	E	F	G
22		PGA	PGA	PGA	PGA	PGA	PGA
23	Site Class	0.25	0.5	0.75	1	1.25	1.5
24	A						
25	B						
26	C	1.3	1.3	1.2	1.2	1.2	1.2
27	D	1.6	1.4	1.2	1.1	1	1
28	E						

Fv

	A	B	C	D	E	F	G
31		PGA	PGA	PGA	PGA	PGA	PGA
32	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
33	A						
34	B						
35	C	1.5	1.5	1.5	1.5	1.5	1.4
36	D	2.4	2.2	2	1.9	1.8	1.7
37	E						

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.202	0.434	1.398	0.282	1.166	0.506	1.200	0.242	1.200	0.521
6	Ss	0.2	0.455	0.988	1.436	0.654	1.105	1.092	1.300	0.592	1.200	1.186
7	S1	1	0.110	0.284	2.380	0.262	2.032	0.577	1.500	0.165	1.500	0.426

	M	N	O	P	Q
10		975 year RP		210 year RP	
11		SEE	SEE	FEE	FEE
12	**Parameter**	**Value**	**Value**	**Value**	**Value**
13	Site Class	D	C	D	C
14	Peak Ground Acceleration (PGA)	0.434g	0.434g	0.202g	0.202g
15	F_{PGA}	1.166	1.200	1.398	1.200
16	Site-Adjusted Peak Ground Acceleration (A_S)	0.506g	0.521g	0.282g	0.242g
17	Short-period (0.2 second) spectral acceleration (S_S)	0.988g	0.988g	0.455g	0.455g
18	Site coefficient (Fa)	1.105	1.200	1.436	1.300
19	Short Period design response acceleration (S_{DS}) = S_S x Fa	1.092g	1.186g	0.654g	0.592g
20	1.0 second period spectral acceleration (S_1)	0.284g	0.284g	0.11g	0.11g
21	Site coefficient (Fv)	2.032	1.500	2.380	1.500
22	1.0 second design response acceleration S_{D1} = S_1 x Fv	0.577g	0.426g	0.262g	0.165g
23	Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G
12		Fpga					
13		PGA	PGA	PGA	PGA	PGA	PGA
14	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
15	A						
16	B						
17	C	1.3	1.2	1.2	1.2	1.2	1.2
18	D	1.6	1.4	1.3	1.2	1.1	1.1
19	E						
20							
21		Fa					
22		PGA	PGA	PGA	PGA	PGA	PGA
23	Site Class	0.25	0.5	0.75	1	1.25	1.5
24	A						
25	B						
26	C	1.3	1.3	1.2	1.2	1.2	1.2
27	D	1.6	1.4	1.2	1.1	1	1
28	E						
29							
30		Fv					
31		PGA	PGA	PGA	PGA	PGA	PGA
32	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
33	A						
34	B						
35	C	1.5	1.5	1.5	1.5	1.5	1.4
36	D	2.4	2.2	2	1.9	1.8	1.7
37	E						

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.200	0.431	1.400	0.280	1.169	0.504	1.200	0.240	1.200	0.517
6	Ss	0.2	0.451	0.98	1.439	0.649	1.108	1.086	1.300	0.587	1.200	1.176
7	S1	1	0.109	0.283	2.382	0.260	2.034	0.576	1.500	0.164	1.500	0.425

Fpga

	PGA	PGA	PGA	PGA	PGA	PGA
Site Class	0.1	0.2	0.3	0.4	0.5	0.6
A						
B						
C	1.3	1.2	1.2	1.2	1.2	1.2
D	1.6	1.4	1.3	1.2	1.1	1.1
E						

Fa

	PGA	PGA	PGA	PGA	PGA	PGA
Site Class	0.25	0.5	0.75	1	1.25	1.5
A						
B						
C	1.3	1.3	1.2	1.2	1.2	1.2
D	1.6	1.4	1.2	1.1	1	1
E						

Fv

	PGA	PGA	PGA	PGA	PGA	PGA
Site Class	0.1	0.2	0.3	0.4	0.5	0.6
A						
B						
C	1.5	1.5	1.5	1.5	1.5	1.4
D	2.4	2.2	2	1.9	1.8	1.7
E						

	975 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.431g	0.431g	0.2g	0.2g
F_{PGA}	1.169	1.200	1.400	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.504g	0.517g	0.28g	0.24g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.451g	0.451g
Site coefficient (Fa)	1.108	1.200	1.439	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.649g	0.587g
1.0 second period spectral acceleration (S_1)	0.283g	0.283g	0.109g	0.109g
Site coefficient (Fv)	2.034	1.500	2.382	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.576g	0.425g	0.26g	0.164g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.198	0.422	1.403	0.278	1.178	0.497	1.202	0.238	1.200	0.506
6	Ss	0.2	0.447	0.959	1.442	0.645	1.116	1.071	1.300	0.581	1.200	1.151
7	S1	1	0.108	0.278	2.383	0.258	2.044	0.568	1.500	0.163	1.500	0.417

14		Fpga					
15		PGA	PGA	PGA	PGA	PGA	PGA
16	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
17	A						
18	B						
19	C	1.3	1.2	1.2	1.2	1.2	1.2
20	D	1.6	1.4	1.3	1.2	1.1	1.1
21	E						

23		Fa					
24		PGA	PGA	PGA	PGA	PGA	PGA
25	Site Class	0.25	0.5	0.75	1	1.25	1.5
26	A						
27	B						
28	C	1.3	1.3	1.2	1.2	1.2	1.2
29	D	1.6	1.4	1.2	1.1	1	1
30	E						

32		Fv					
33		PGA	PGA	PGA	PGA	PGA	PGA
34	Site Class	0.1	0.2	0.3	0.4	0.5	0.6
35	A						
36	B						
37	C	1.5	1.5	1.5	1.5	1.5	1.4
38	D	2.4	2.2	2	1.9	1.8	1.7
39	E						

M	N	O	P	Q
	975 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.422g	0.422g	0.198g	0.198g
F_{PGA}	1.178	1.200	1.403	1.202
Site-Adjusted Peak Ground Acceleration (A_S)	0.497g	0.506g	0.278g	0.238g
Short-period (0.2 second) spectral acceleration (S_S)	0.959g	0.959g	0.447g	0.447g
Site coefficient (Fa)	1.116	1.200	1.442	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.071g	1.151g	0.645g	0.581g
1.0 second period spectral acceleration (S_1)	0.278g	0.278g	0.108g	0.108g
Site coefficient (Fv)	2.044	1.500	2.383	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.568g	0.417g	0.258g	0.163g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

JOB NO. PS19203160

COMPUTED BY E.Kermani

PROJECT I-405

DATE 4/5/2021

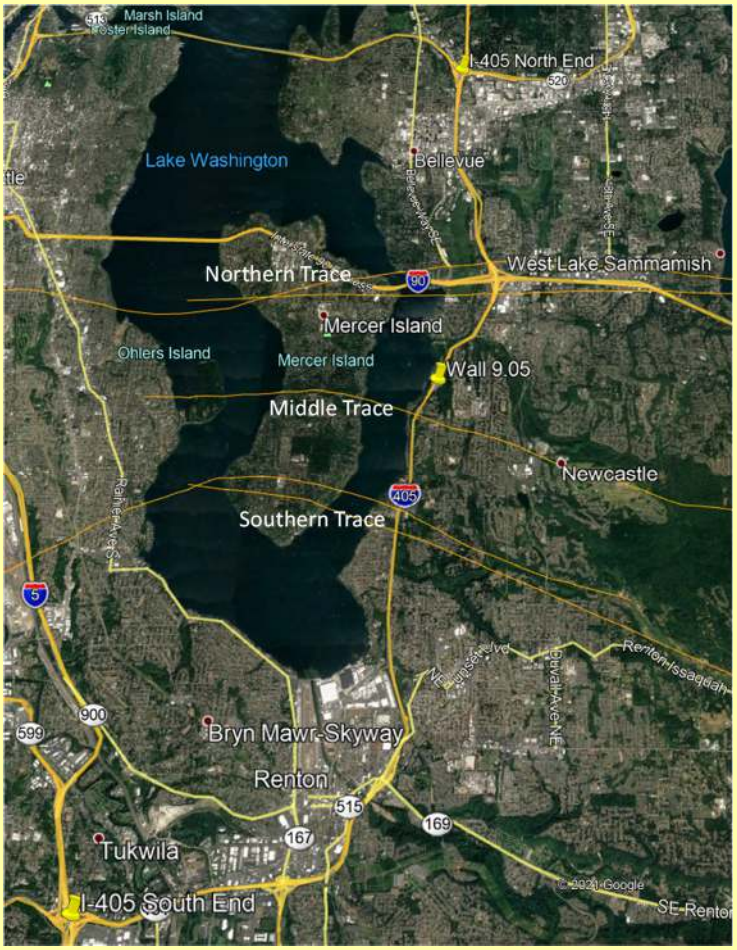
SUBJECT Site Class, Wall 9.05R-A

CHECKED BY Jim French Date 4/6/2021

1.0 Background:

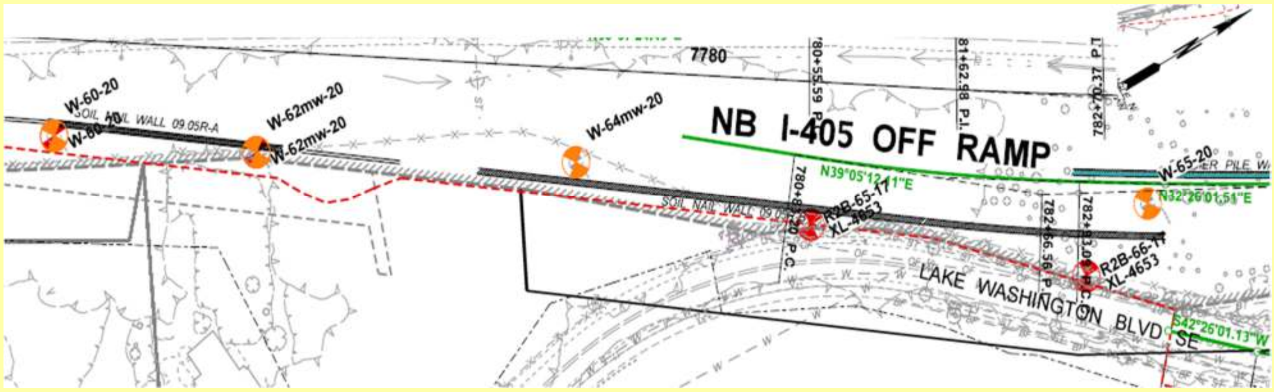
Wood is providing geotechnical engineering services for the I-405 improvements project. Below is an image of the alignment with the southern and northern ends marked and also the location of the Wall 9.05R-A. Also shown are fault traces that cross the alignment for the Seattle fault (northern, middle, and southern traces).

Figure 1: Project Alignment with Fault Traces



There are 6 explorations along wall 9.05R-A as shown in the Figure 2.

Figure 2: Wall 9.05R-A Boring Plan



Here is a summary of information for each of these explorations:

Table 1: Summary of explorations along the wall 9.05R-A

Boring	Year Drilled	Total Depth (ft)	Groundsurface Elevation, NAVD88 (ft)	Hammer Efficiency (%)
R2B-65-17	2017	79.5	173.4	88
R2B-66-17	2017	79.5	171.6	88
W-60-20	2020	40.6	156.3	88
W-62mw-20	2020	46.5	155.5	88
W-64mw-20	2020	61.5	151.2	88
W-65-20	2020	51.5	175.1	88

2.0 Problem:

Evaluate the Site Class for the site to use in the determination of the seismic hazard parameters for the structure.

3.0 Approach:

3.1 Seismic Hazard

A site should be classified as A though F in accordance with the site class definitions in Table 2. Sites should be classified by their stiffness as determined by the shear wave velocity in the upper 100 ft., Standard Penetration Test (SPT) blow counts, or undrained shear strengths of soil samples from the borings or CPTs.

To determine the site class the methods in AASHTO LRFD BDS Section 3.10.3.1 are used. Here are the site class definitions:

Table 2: Site Class Definitions

Table 3.10.3.1-1—Site Class Definitions

Site Class	Soil Type and Profile
A	Hard rock with measured shear wave velocity, $\overline{v}_s > 5{,}000$ ft/s
B	Rock with 2,500 ft/sec < $\overline{v}_s$ < 5,000 ft/s
C	Very dense soil and soil rock with 1,200 ft/sec < $\overline{v}_s$ < 2,500 ft/s, or with either $\overline{N}$ > 50 blows/ft, or $\overline{s}_u$ > 2.0 ksf
D	Stiff soil with 600 ft/s < $\overline{v}_s$ < 1,200 ft/s, or with either 15 < $\overline{N}$ < 50 blows/ft, or 1.0 < $\overline{s}_u$ < 2.0 ksf
E	Soil profile with $\overline{v}_s$ < 600 ft/s or with either $\overline{N}$ < 15 blows/ft or $\overline{s}_u$ < 1.0 ksf, or any profile with more than 10.0 ft of soft clay defined as soil with *PI* > 20, *w* > 40 percent and $\overline{s}_u$ < 0.5 ksf
F	Soils requiring site-specific evaluations, such as: • Peats or highly organic clays (*H* > 10.0 ft of peat or highly organic clay where *H* = thickness of soil) • Very high plasticity clays (*H* > 25.0 ft with *PI* > 75) • Very thick soft/medium stiff clays (*H* >120 ft)

There is no shear wave velocity measurement available at Walls 9.05R-A and 9.05R-B. The average Standard Penetration Test (SPT) blow count (blows/ft) for the upper 100 ft of the soil profile ($\overline{N}$) from the borings at the site will be used to determine the site class.

4.0 Evaluations:

4.1 Seismic Hazard Evaluation

Average Standard Penetration Test (SPT) blow count (blows/ft) $\overline{N}$ for the top 100 ft is determined as:

$$\overline{N} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{N_i}} \tag{1}$$

Where, N_i is standard penetration test blow count of each layer (not to exceed 100 blows/ft), d_i is thickness of a layer in feet and n is 100 feet.

The average Standard Penetration Test (SPT) blow count (blows/ft) ($\overline{N}$) for the upper 100 ft of the soil profile for each boring were evaluated in the Site Class.xlsx on tab 'Site Class', using the inverse average calculation method defined above from AASHTO Guide Specifications for LRFD Seismic Bridge Design Section 3.4.2.2. The data from the calculation of $N_{1,60}$ was copied into columns A to C. Columns D to H then calculate the average blowcount in the upper 100 feet. For borings that did not reach 100 feet the last blowcount was assumed to be representative of the soils below. Borings less than 50 feet in depth were ignored in this calculation. Four borings were deeper than 50 feet along wall 9.05. Values for the average blowcount was calculated as 72. The site is determined to be Site Class C (very dense soil and soil rock, because $\overline{N}$ is greater than 50).

Here is an example calculation of the average Standard Penetration Test (SPT) blow count (blows/ft) ($\bar{N}$) for the upper 100 ft of the soil profile for a boring based on the above discussed method as a check for the spreadsheet. Note that the boring depth is 70 ft. and did not reach 100 feet, hence the last blowcount (N) value was assumed to be representative of the soils below. The first three columns were entered from the boring information.

Boring	Top Depth (ft.)	N60	N60 capped at 100	d_i	d_i/N_i	$\Sigma(d_i/N_i)$	N_{avg}
Example	2	7	7	4.5	0.643	0.643	
Example	7	11	11	5	0.455	1.097	
Example	12	12	12	6.5	0.542	1.639	
Example	20	20	20	9	0.450	2.089	
Example	30	25	25	10	0.400	2.489	
Example	40	50	50	10	0.200	2.689	
Example	50	110	100	10	0.100	2.789	
Example	60	80	80	10	0.125	2.914	
Example	70	70	70	35	0.500	3.414	29

As it was shown in the table, N60 was measured as 20 at 20 ft.

Column E: Layer thickness d_i is measured as: 25-16=9 ft.

Column F: d_i/N_i = 9/20=0.45

Column G: Sum of d_i/N from ground surface: $\Sigma(d_i/N_i)$ = 0.643+0.455+0.542+0.450 = 2.089

Column H: Nave = $\Sigma(d_i)/\ \Sigma(d_i/N_i)$ =100/ 3.414 = 29

5.0 Conclusions:

The site is classified as Site Class C for seismic hazard evaluations.

6.0 Attachments:

No	Name of document	Tabs (if any)	Pages
1	Site Class – 9.05.xlsx	*Site Class*	-

Boring Number	Top Depth (ft)	N60	N60 capped at 100	Thickness (ft)	d/N	Running Sum of d/N	Average N
R2B-65-17	4.0	75	75	5.50	0.07	0.07	
R2B-65-17	7.0	196	100	2.50	0.03	0.10	
R2B-65-17	9.0	125	100	2.50	0.03	0.12	
R2B-65-17	12.0	125	100	2.50	0.03	0.15	
R2B-65-17	14.0	125	100	3.50	0.04	0.18	
R2B-65-17	19.0	139	100	5.00	0.05	0.23	
R2B-65-17	24.0	233	100	5.00	0.05	0.28	
R2B-65-17	29.0	183	100	5.00	0.05	0.33	
R2B-65-17	34.0	147	100	5.00	0.05	0.38	
R2B-65-17	39.0	170	100	5.00	0.05	0.43	
R2B-65-17	44.0	128	100	5.00	0.05	0.48	
R2B-65-17	49.0	147	100	5.00	0.05	0.53	
R2B-65-17	54.0	147	100	5.00	0.05	0.58	
R2B-65-17	59.0	147	100	5.00	0.05	0.63	
R2B-65-17	64.0	147	100	5.00	0.05	0.68	
R2B-65-17	69.0	183	100	5.50	0.06	0.74	
R2B-65-17	75.0	147	100	5.00	0.05	0.79	
R2B-65-17	79.0	147	100	23.00	0.23	1.02	98
R2B-66-17	4.0	46	46	5.50	0.12	0.12	
R2B-66-17	7.0	70	70	2.50	0.04	0.15	
R2B-66-17	9.0	105	100	2.50	0.03	0.18	
R2B-66-17	12.0	125	100	2.50	0.03	0.20	
R2B-66-17	14.0	208	100	3.50	0.04	0.24	
R2B-66-17	19.0	139	100	5.00	0.05	0.29	
R2B-66-17	24.0	233	100	5.00	0.05	0.34	
R2B-66-17	29.0	367	100	5.00	0.05	0.39	
R2B-66-17	34.0	367	100	5.00	0.05	0.44	
R2B-66-17	39.0	147	100	5.00	0.05	0.49	
R2B-66-17	44.0	106	100	5.00	0.05	0.54	
R2B-66-17	49.0	82	82	5.00	0.06	0.60	
R2B-66-17	54.0	104	100	5.00	0.05	0.65	
R2B-66-17	59.0	113	100	5.00	0.05	0.70	
R2B-66-17	64.0	147	100	5.00	0.05	0.75	
R2B-66-17	69.0	147	100	5.00	0.05	0.80	
R2B-66-17	74.0	147	100	5.00	0.05	0.85	
R2B-66-17	79.0	147	100	23.50	0.24	1.09	92
W-60-20	2.5	9	9	3.75	0.43	0.43	
W-60-20	5.0	11	11	2.50	0.24	0.66	
W-60-20	7.5	47	47	2.50	0.05	0.72	
W-60-20	10.0	74	74	3.75	0.05	0.77	
W-60-20	15.0	130	100	5.00	0.05	0.82	
W-60-20	20.0	120	100	5.00	0.05	0.87	
W-60-20	25.0	109	100	5.00	0.05	0.92	
W-60-20	30.0	293	100	5.00	0.05	0.97	
W-60-20	35.0	147	100	5.00	0.05	1.02	
W-60-20	40.0	880	100	62.50	0.63	1.64	
W-62mw-20	2.5	28	28	3.75	0.14	0.14	
W-62mw-20	5.0	36	36	2.50	0.07	0.21	
W-62mw-20	7.5	85	85	2.50	0.03	0.23	
W-62mw-20	10.0	74	74	3.75	0.05	0.29	
W-62mw-20	15.0	139	100	5.00	0.05	0.34	
W-62mw-20	20.0	167	100	5.00	0.05	0.39	
W-62mw-20	25.0	209	100	5.00	0.05	0.44	
W-62mw-20	30.0	440	100	5.00	0.05	0.49	
W-62mw-20	35.0	103	100	5.00	0.05	0.54	
W-62mw-20	40.0	91	91	5.00	0.06	0.59	
W-62mw-20	45.0	79	79	57.50	0.73	1.32	
W-64mw-20	2.5	8	8	3.75	0.49	0.49	
W-64mw-20	5.0	15	15	2.50	0.16	0.65	
W-64mw-20	7.5	27	27	2.50	0.09	0.74	
W-64mw-20	10.0	24	24	3.75	0.16	0.90	
W-64mw-20	15.0	56	56	5.00	0.09	0.99	
W-64mw-20	20.0	66	66	5.00	0.08	1.07	
W-64mw-20	25.0	75	75	5.00	0.07	1.13	
W-64mw-20	30.0	87	87	5.00	0.06	1.19	
W-64mw-20	35.0	101	100	5.00	0.05	1.24	
W-64mw-20	40.0	103	100	5.00	0.05	1.29	
W-64mw-20	45.0	132	100	5.00	0.05	1.34	
W-64mw-20	50.0	120	100	5.00	0.05	1.39	
W-64mw-20	55.0	97	97	5.00	0.05	1.44	
W-64mw-20	60.0	98	98	42.50	0.43	1.88	53
W-65-20	2.0	13	13	3.50	0.27	0.27	
W-65-20	5.0	18	18	2.75	0.16	0.42	
W-65-20	7.5	12	12	2.50	0.21	0.64	
W-65-20	10.0	10	10	3.75	0.38	1.01	
W-65-20	15.0	10	10	5.00	0.51	1.52	
W-65-20	20.0	139	100	5.00	0.05	1.57	
W-65-20	25.0	139	100	5.00	0.05	1.62	
W-65-20	30.0	147	100	5.00	0.05	1.67	
W-65-20	35.0	293	100	5.00	0.05	1.72	
W-65-20	40.0	147	100	5.00	0.05	1.77	
W-65-20	45.0	293	100	5.00	0.05	1.82	
W-65-20	50.0	100	100	52.50	0.53	2.35	43
Example	2.0	7	7	4.50	0.64	0.64	
Example	7.0	11	11	5.00	0.45	1.10	
Example	12.0	12	12	6.50	0.54	1.64	
Example	20.0	20	20	9.00	0.45	2.09	
Example	30.0	25	25	10.00	0.40	2.49	
Example	40.0	50	50	10.00	0.20	2.69	
Example	50.0	110	100	10.00	0.10	2.79	
Example	60.0	80	80	10.00	0.13	2.91	
Example	70.0	70	70	35.00	0.50	3.41	29

Average N	Site Class
72	C

Table 3.10.3.1-1—Site Class Definitions

Site Class	Soil Type and Profile
A	Hard rock with measured shear wave velocity, $\bar{v}_s > 5{,}000$ ft/s
B	Rock with 2,500 ft/sec $< \bar{v}_s < 5{,}000$ ft/s
C	Very dense soil and soil rock with 1,200 ft/sec $< \bar{v}_s < 2{,}500$ ft/s, or with either $\bar{N} > 50$ blows/ft, or $\bar{s}_u > 2.0$ ksf
D	Stiff soil with 600 ft/s $< \bar{v}_s <$ 1,200 ft/s, or with either $15 < \bar{N} < 50$ blows/ft, or $1.0 < \bar{s}_u < 2.0$ ksf
E	Soil profile with $\bar{v}_s < 600$ ft/s or with either $\bar{N} < 15$ blows/ft or $\bar{s}_u < 1.0$ ksf, or any profile with more than 10.0 ft of soft clay defined as soil with $PI > 20$, $w > 40$ percent and $\bar{s}_u < 0.5$ ksf
F	Soils requiring site-specific evaluations, such as: • Peats or highly organic clays ($H > 10.0$ ft of peat or highly organic clay where H = thickness of soil) • Very high plasticity clays ($H > 25.0$ ft with $PI > 75$) • Very thick soft/medium stiff clays ($H > 120$ ft)

JOB NO. PS19203160

COMPUTED BY K. Burlingham

PROJECT I-405

DATE 9/14/2020

SUBJECT Seismic Coefficient (k_h) Values, Wave Scattering

CHECKED BY E. Kermani Date: 10/7/20

1.0 Background:

Wood is providing geotechnical engineering services for the I-405 improvements project.

2.0 Problem:

Evaluate seismic coefficient (k_h) values to be used for walls/slopes that are over 20 feet in height with an allowable displacement of 1 to 2 inches for seismic earth pressure and pseudo-static global stability evaluations.

3.0 Approach:

The controlling specifications for the seismic coefficient evaluations are the WSDOT Geotechnical Design Manual (GDM) Section 15-4.10 for wall seismic earth pressures and Chapter 6-4.3.2 for global slope stability pseudo-static evaluations.

The typical value for k_h (seismic coefficient) is 0.5*As (about 0.25g for most of the alignment) which corresponds to movements of 1 to 2 inches per GDM sections 15-4.10 and 6-4.3.2.

If desired though the methods from AASHTO LRFD BDS Appendix A11.5 can be used to reduce the k_h value below 0.5*As based on the allowable displacements above being larger than the typical 1 to 2 inches or wave scattering. Appendix A11.5 is for walls though it applies to slopes as well as the equations are the same as those included in Kavazanjian et al. (2011) that is referenced in GDM Section 6-4.3.2 for slopes.
Both Appendix A11.5 of AASHTO LRFD BDS and Kavazanjian et al. (2011) contain the same equations for wave scattering. Kavazanjian et al. (2011) contains the following detailed procedure to determine the reduced k_h value for a given wall/slope height and site specific PGA spectral acceleration.

1) Conduct static slope stability analyses using appropriate resistance factors to confirm that slope performance meets static loading requirements.

2) Establish the upper bound value of the seismic coefficient k_{max} (= F_{pga} PGA) and the site-adjusted spectral acceleration at one second, F_vS_1, from the AASHTO ground motions maps for a 1,000-year return period and the Site Class-dependent AASHTO site factors.

3) Modify k_{max} to find the average peak acceleration accounting for slope height effects, k_{av} (= α k_{max}), in accordance with Equations 6-2 through 6-4.

$$k_{av} = \alpha \cdot k_{max} \qquad 6\text{-}2$$

$$\alpha = 1 + 0.01 \cdot H \cdot (0.5 \cdot \beta - 1) \qquad 6\text{-}3$$

where H = slope height (feet) and β is a function of the shape of the acceleration response spectrum and is given by:

$$\beta = F_v \cdot S_1 / k_{max} \qquad 6\text{-}4$$

4) Reduce k_{av} by a factor of 0.5 to find k_S (assuming 1 to 2 inches of permanent displacement are permissible). If larger permanent displacements are acceptable, further reductions in k_{av} are possible, but these would have to be determined by conducting separate calibrations studies between the resulting displacement and the ratio of k_S to k_{av}, as discussed in Section 6.2.3.

5) Conduct a conventional slope stability analysis using $k_S = 0.5\ k_{av}$. If the resulting C/D ratio (i.e. the resulting FS) is at least 1.1, the slope meets seismic stability requirements.

4.0 Evaluations:

As determined in the Seismic Hazard calculation for the I-405 project the As (k_{max}) values along the alignment for Site Class D sites range from 0.497g to 0.509g and for Site Class C sites range from 0.506g to 0.526g for the 1,000 year return period SEE level of hazard. S_{D1} (F_v*S_1) values along the alignment for Site Class D sites range from 0.568g to 0.580g and for Site Class C sites range from 0.417g to 0.429g for the 1,000 year return period SEE level of hazard.

Below are the calculations for k_h for the range of As and S_{D1} values for both site classes and along the entire I-405 alignment from Segment 1A to 2B for various wall heights. It is noted that for wall/slope heights below 20 feet the standard value of 0.5*As should be used for k_h per AASHTO LRFD BDS Section A11.5.2. For walls above 60 feet in height AASHTO LRFD BDS recommends a special seismic design instead of using the wave scattering values given in this calculation. For slopes greater than 60 feet the values given in this calculation can be used up to a height of 100 feet per Kavazanjian et al. (2011).

As shown the percent of k_h values are not sensitive to the variation along the alignment for the I-405 project but there is some variation for the two site classes. Thus the average values for each site class given in the right most column should be used. Here is a hand calculation for the first row for checking purposes: $\alpha = 1 + 0.01*20*(0.5*0.568/0.497-1) = 0.91$; $k_h = 0.91*0.5*0.497 = 0.23$g

Site Class D:

Kavazanjian (2011), FHWA-NHI-11-032 Section 6.2.2 and AASHTO A11.5.2

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)
20	0.497	0.568	0.91	0.23
25	0.497	0.568	0.89	0.22
30	0.497	0.568	0.87	0.22
35	0.497	0.568	0.85	0.21
40	0.497	0.568	0.83	0.21
45	0.497	0.568	0.81	0.20

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)	Average k_h (g)	
20	0.509	0.58	0.91	0.23	0.23	
25	0.509	0.58	0.89	0.23	0.22	
30	0.509	0.58	0.87	0.22	0.22	
35	0.509	0.58	0.85	0.22	0.21	
40	0.509	0.58	0.83	0.21	0.21	
45	0.509	0.58	0.81	0.21	0.20	

wood.

SHEET 3 OF 2

JOB NO. PS19203160

COMPUTED BY K. Burlingham

PROJECT I-405

DATE 9/14/2020

SUBJECT Seismic Coefficient (k_h) Values, Wave Scattering

CHECKED BY E. Kermani Date: 10/7/20

Site Class D:

Kavazanjian (2011), FHWA-NHI-11-032 Section 6.2.2 and AASHTO A11.5.2

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)
50	0.497	0.568	0.79	0.20
55	0.497	0.568	0.76	0.19
60	0.497	0.568	0.74	0.18
65	0.497	0.568	0.72	0.18
70	0.497	0.568	0.70	0.17
75	0.497	0.568	0.68	0.17
80	0.497	0.568	0.66	0.16
85	0.497	0.568	0.64	0.16
90	0.497	0.568	0.61	0.15
95	0.497	0.568	0.59	0.15
100	0.497	0.568	0.57	0.14

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)	Average k_h (g)	
50	0.509	0.58	0.78	0.20	0.20	
55	0.509	0.58	0.76	0.19	0.19	
60	0.509	0.58	0.74	0.19	0.19	
65	0.509	0.58	0.72	0.18	0.18	
70	0.509	0.58	0.70	0.18	0.18	
75	0.509	0.58	0.68	0.17	0.17	
80	0.509	0.58	0.66	0.17	0.17	
85	0.509	0.58	0.63	0.16	0.16	
90	0.509	0.58	0.61	0.16	0.15	
95	0.509	0.58	0.59	0.15	0.15	
100	0.509	0.58	0.57	0.15	0.14	

Site Class C:

Kavazanjian (2011), FHWA-NHI-11-032 Section 6.2.2 and AASHTO A11.5.2

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)
20	0.506	0.417	0.88	0.22
25	0.506	0.417	0.85	0.22
30	0.506	0.417	0.82	0.21
35	0.506	0.417	0.79	0.20
40	0.506	0.417	0.76	0.19
45	0.506	0.417	0.74	0.19
50	0.506	0.417	0.71	0.18
55	0.506	0.417	0.68	0.17
60	0.506	0.417	0.65	0.16
65	0.506	0.417	0.62	0.16
70	0.506	0.417	0.59	0.15
75	0.506	0.417	0.56	0.14
80	0.506	0.417	0.53	0.13
85	0.506	0.417	0.50	0.13
90	0.506	0.417	0.47	0.12
95	0.506	0.417	0.44	0.11
100	0.506	0.417	0.41	0.10

Wall/Slope Height (ft)	A_s (g)	S_{D1} (g)	α	k_h (g)	Average k_h (g)	
20	0.526	0.429	0.88	0.23	0.23	
25	0.526	0.429	0.85	0.22	0.22	
30	0.526	0.429	0.82	0.22	0.21	
35	0.526	0.429	0.79	0.21	0.20	
40	0.526	0.429	0.76	0.20	0.20	
45	0.526	0.429	0.73	0.19	0.19	
50	0.526	0.429	0.70	0.19	0.18	
55	0.526	0.429	0.67	0.18	0.17	
60	0.526	0.429	0.64	0.17	0.17	
65	0.526	0.429	0.62	0.16	0.16	
70	0.526	0.429	0.59	0.15	0.15	
75	0.526	0.429	0.56	0.15	0.14	
80	0.526	0.429	0.53	0.14	0.14	
85	0.526	0.429	0.50	0.13	0.13	
90	0.526	0.429	0.47	0.12	0.12	
95	0.526	0.429	0.44	0.12	0.11	
100	0.526	0.429	0.41	0.11	0.11	

In Association with

Appendix E-1.2
Calculation of Yield Accelerations & Seismic Coefficients Using Anderson Method

I-405 R2B Express Toll Lanes
Segment 2A Wall 09.35L

Seismic Coefficients
Soldier Pile Wall

Date: June 2021

Prepared For: ***Flatiron-Lane Joint Venture***

Prepared By: wood.

1.0 SEISMIC PROPERTIES USED FOR DESIGN

Design peak ground acceleration: $A_s := 0.517$

1-second period spectral acceleration: $S_1 := 0.283$

Site coefficient: $F_v := 1.500$

Beta coefficient for wave scattering: $\beta := \dfrac{F_v \cdot S_1}{A_s} = 0.8$

2.0 WAVE SCATTERING

Height of Slope/Wall:

$$H := \begin{pmatrix} 20 \\ 25 \\ 30 \\ 35 \\ 40 \\ 45 \\ 50 \\ 55 \\ 60 \end{pmatrix} ft$$

Slope height reductin factor:

$$\alpha := 1 + 0.01\frac{H}{ft}\cdot(0.5\cdot\beta - 1) = \begin{pmatrix} 0.882 \\ 0.853 \\ 0.823 \\ 0.794 \\ 0.764 \\ 0.735 \\ 0.705 \\ 0.676 \\ 0.646 \end{pmatrix}$$

AASHTO A11.5.2

Peak ground acceleration reduced for wave scattering:

$$k_{av} := \alpha \cdot A_s = \begin{pmatrix} 0.456 \\ 0.441 \\ 0.426 \\ 0.410 \\ 0.395 \\ 0.380 \\ 0.365 \\ 0.349 \\ 0.334 \end{pmatrix}$$

3.0 SEISMIC COEEFICIENT WITH DEFLECTION

$$\log d = -1.51 - 0.74\log\left(\frac{ky}{kh0}\right) + 3.27\log\left(1 - \frac{ky}{kh0}\right) - 0.80 log kh0 + 1.59\log(PGV)$$

AASHTO A11.5.2 (Anderson 2008)

Peak ground velocity: $PGV := 38 \cdot F_v \cdot S_1 = 16.131$

For 1 in Deflection: $d_1 := 1$ in

Yield acceleration: $k_{y1} := 0.24$ By trial and error to get deflection about 1 in

Coefficient:

$$C_1 := -1.51 - 0.74\log\left(\frac{k_{y1}}{A_s}\right) + 3.27\cdot\log\left(1 - \frac{k_{y1}}{A_s}\right) - 0.80\cdot\log(A_s) + 1.59\cdot\log(PGV) = -0.000$$

Calculated deflection, d: $10^{C_1} = 1.000$ This deflection is close enough to our estimate of 1 in

Design seismic horizontal coefficient:

$$k_{h1} := \alpha \cdot k_{y1} = \begin{pmatrix} 0.212 \\ 0.205 \\ 0.198 \\ 0.190 \\ 0.183 \\ 0.176 \\ 0.169 \\ 0.162 \\ 0.155 \end{pmatrix}$$

For height (ft): $\begin{pmatrix} 20 \\ 25 \\ 30 \\ 35 \\ 40 \\ 45 \\ 50 \\ 55 \\ 60 \end{pmatrix}$

For 0.5 in Deflection: $d_{0.5} := 0.5$ in

Yield acceleration: $k_{y0.5} := 0.284$ By trial and error to get deflection about 0.5 in

Coefficient:

$$C_{0.5} := -1.51 - 0.74\log\left(\frac{k_{y0.5}}{A_s}\right) + 3.27\cdot\log\left(1 - \frac{k_{y0.5}}{A_s}\right) - 0.80\cdot\log(A_s) + 1.59\cdot\log(PGV) = -0.300$$

Calculated deflection, d: $10^{C_{0.5}} = 0.501$ This deflection is close enough to our estimate of 0.5 in

Design seismic horizontal coefficient:

$$k_{h0.5} := \alpha \cdot k_{y0.5} = \begin{pmatrix} 0.251 \\ 0.242 \\ 0.234 \\ 0.225 \\ 0.217 \\ 0.209 \\ 0.200 \\ 0.192 \\ 0.184 \end{pmatrix}$$

For height (ft): $\begin{pmatrix} 20 \\ 25 \\ 30 \\ 35 \\ 40 \\ 45 \\ 50 \\ 55 \\ 60 \end{pmatrix}$

For 0.1 in Deflection: $d_{0.1} := 0.1$ in

Yield acceleration: $k_{y0.1} := 0.366$ By trial and error to get deflection about 0.1 in

Coefficient: $C_{0.1} := -1.51 - 0.74\log\left(\frac{k_{y0.1}}{A_s}\right) + 3.27\cdot\log\left(1 - \frac{k_{y0.1}}{A_s}\right) - 0.80\cdot\log(A_s) + 1.59\cdot\log(PGV) = -0.997$

Calculated deflection, d: $10^{C_{0.1}} = 0.101$ This deflection is close enough to our estimate of 0.1 in

Design seismic horizontal coefficient:

$$k_{h0.1} := \alpha\cdot k_{y0.1} = \begin{pmatrix} 0.323 \\ 0.312 \\ 0.301 \\ 0.290 \\ 0.280 \\ 0.269 \\ 0.258 \\ 0.247 \\ 0.237 \end{pmatrix}$$

For height (ft):

$$\begin{pmatrix} 20 \\ 25 \\ 30 \\ 35 \\ 40 \\ 45 \\ 50 \\ 55 \\ 60 \end{pmatrix}$$

In Association with

Appendix E-2
Global Stability Results
& Earth Pressure Diagrams

1 **Table E-1: Stability Analysis Results – Station 2+60 of Wall 9.05R-A**

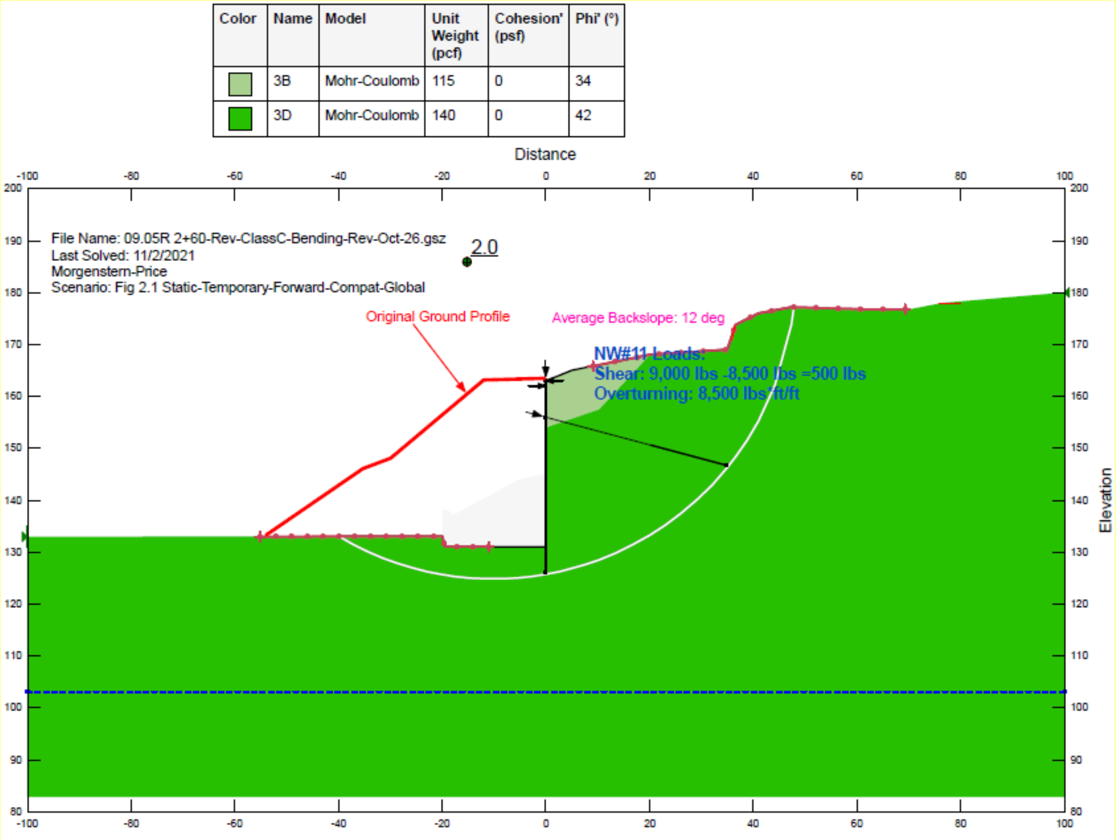
Analysis		FS	Remarks	Figure[1]
1	Verification of soldier pile minimum embedment at future compatibility (Static)	2.0	A minimum embedment of 5 feet below the anticipated future temporary cut was considered and checked along a potential slip surface passing below the shaft tips. The FS > 1.3 indicates sufficient stability against the noted failure mechanism and minimum pile shaft embedment considered. Deeper embedment may be necessary to meet the soldier pile requirements to support the loads of the retaining wall, the noise wall, and the vertical projection of the anchor loads. Static loads from NW11 modeled by a net shear force of 500 lbs/ft and a set of complementary point loads of 8,100 pounds spaced at 1.0 foot distance to model the factored overturning moment.	E-2.1
2	Global stability of the soil mass containing the wall (Long-Term Static)	2.3	Higher value of FS is due to significant wall embedment in the present wall arrangement. Static loads from NW11 modeled as above (Analysis #1).	E-2.2
3	Global stability of the soil mass containing the wall (Pseudo-static assuming 1.0 to 2.0 inches slope and wall seismic movement)	1.6	A higher FS than minimum required due to the pile embedment for the future wall arrangement. A net shear force of 5,100 lbs/ft and overturning moment of 50,300 lbs*ft/ft modelled by two complementary point loads of 50,300 pounds spaced at 1.0 foot distance were included at the top of retaining wall/base of noise wall to account for the seismic loads from NW11 sitting on top of the soldier pile wall.	E-2.3
4	Project arrangement: through-wall – Service 1 (Static) using M-P and Spencer method	1.3	Analysis conducted to assess the minimum unfactored shear wall and anchor pullout resistances necessary to develop the required FS=1.3 for global stability along slip surfaces crossing the wall and anchors. The resistances obtained (1,500 lbs/ft for each of the resisting components) represent only one of the multiple combinations possible. No changes in results between M-P and Spencer methods.	E-2.4 and E-2.5
5	Project Arrangement-Extreme 1: Using the pseudo-static slope approach (M-P method)	1.1	Pseudo-static slope model with a seismic coefficient k_h = 0.21, determined on the basis of a seismic slope and wall movement of 1.0 to 2.0 inches. The analysis illustrates one of the multiple possible combinations of the resistances required for the pile shaft and anchor is 1,500 lbs/ft for each resisting component using the M-P analysis method.	E-2.6

Analysis		FS	Remarks	Figure[1]
6	Similar to Analysis 5 using Spencer Method	1.1	Analysis conducted as a cross-check of Analysis 5 by a different method as per Project GDM. In this case, the Spencer method led to tangibly increased demands for the combination anchor resistances (from 1,500 lbs/ft to 3,500 lbs/ft) and pile shaft resistances (from 1,500 lbs/ft to 2,500 lbs/ft) over the M-P method. This scenario governs the anchor and shaft design for global stability. However, other combinations of structural resistances of the pile shaft and anchors may be available to ensure the required factor of safety for global stability as illustrated in Analyses 7 and 8.	E-2.7
7	Similar to Analysis 6 example of different structural resistance designs	1.1	Same as Analysis 6 using a different combination of strength imparted to the pile shaft (3,000 lbs/ft) and anchor pullout resistance (3,000 lbs/ft), leading to same FS=1.1 for the global stability under seismic loads using the Spencer method.	E-2.8
8	Similar to Analyses 5 example using cantilevered wall arrangement	>1.3 Static 1.1 Seismic	This is an illustration for a cantilever arrangement. Seismic case dictates the design requiring a significantly increased shaft resistance to 8,000 lbs/ft. The shaft embedment shown is valid for the global stability. The actual embedment may need to be increased subject to structural design of the cantilevered wall. The cantilever option for exposed wall face exceeding 10 feet in height may not be practical for permanent structures due to potential for significant static deformation. Subject to acceptance of the wall deformation performance assessed by the structural design, the shaft embedment may need to be increased beyond the length shown herein subject to the shaft structural design to lateral loads.	E-2.9
9	GLE method for determination of static and seismic earth pressure coefficients for current project wall heights	1.0	Once the equilibrium resisting wall force was determined, an average unit weight of 127.5 pounds per cubic foot was assumed for the stratified ESU 3B over ESU 3D deposits of approximately equal heights in order to back-calculate K_a and K_{ae}. Pseudo static K_{ae} was determined for two sets of seismic deformations: 0.1 inch and 1.0 to 2.0 inches. The slip surfaces resulted slightly curved. The bonded section of the anchor should be placed behind the critical slip surface. The flattest base angle of just below 41 degrees was determined for the most critical slip surface.	E-2.10

Analysis		FS	Remarks	Figure[1]
10	GLE method for determination of seismic earth pressures for forward compatibility wall heights	1.0	A geometric average unit weight of 132 pounds per cubic foot was assumed for the stratified ESU 3B over ESU 3D deposits of heights of approximately one third and two thirds of the total height, respectively, in order to back-calculate K_a and K_{ae} from the total limit equilibrium load. Pseudo static K_{ae} was determined for two sets of seismic deformations: 0.1 inch and 1.0 to 2.0 inches. The slip surfaces resulted slightly curved. The bonded section of the anchor should be placed behind the critical slip surface. The flattest base angle of just below 45.6 degrees was determined for the most critical slip surface.	E-2.11

Notes:
1. Figures referenced are located in this appendix.

Abbreviations
ESU = Engineering Stratigraphic Unit
FS = factor of safety
GDM = Geotechnical Design Manual
GLE = General Limit Equilibrium
K_a = active earth pressure coefficient (static)
K_{ae} = active earth pressure coefficient (seismic)
lbs/ft = pounds per foot
lbs*ft/ft = pound-foot per unit length of wall
M-P = Morgenstern-Price
NW11 = noise wall 11

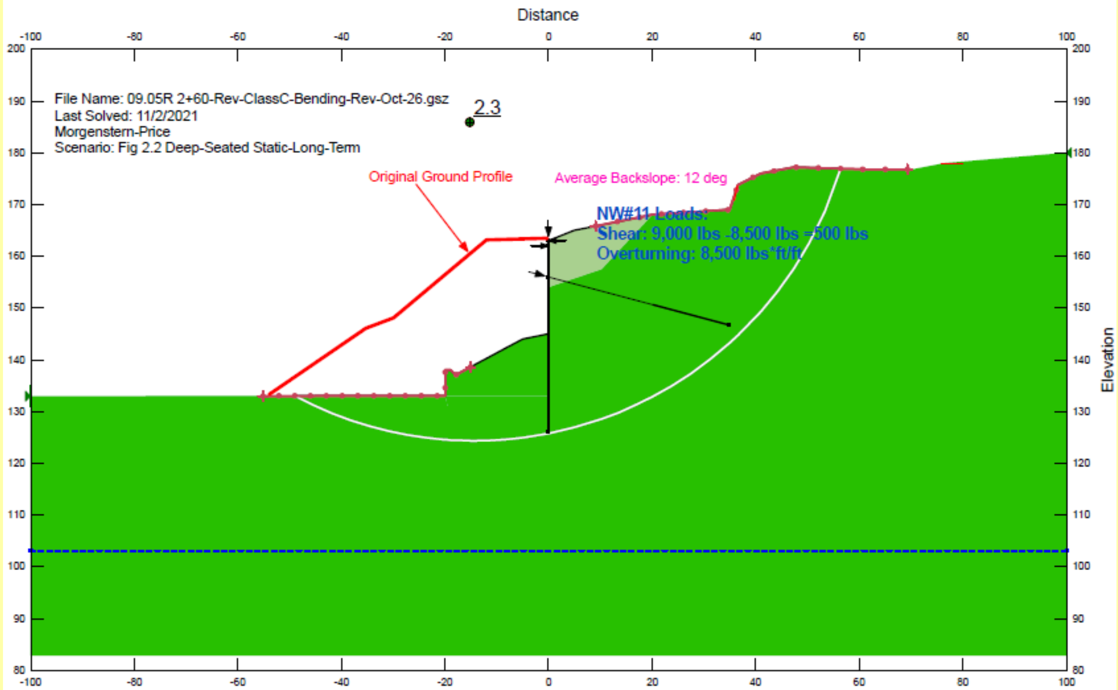


Global stability check to prevent the wall toe "kick-out" during Temporary-Forward Compatibility assuming a minimum soldier pile embedment of 5.0 ft below subgrade.

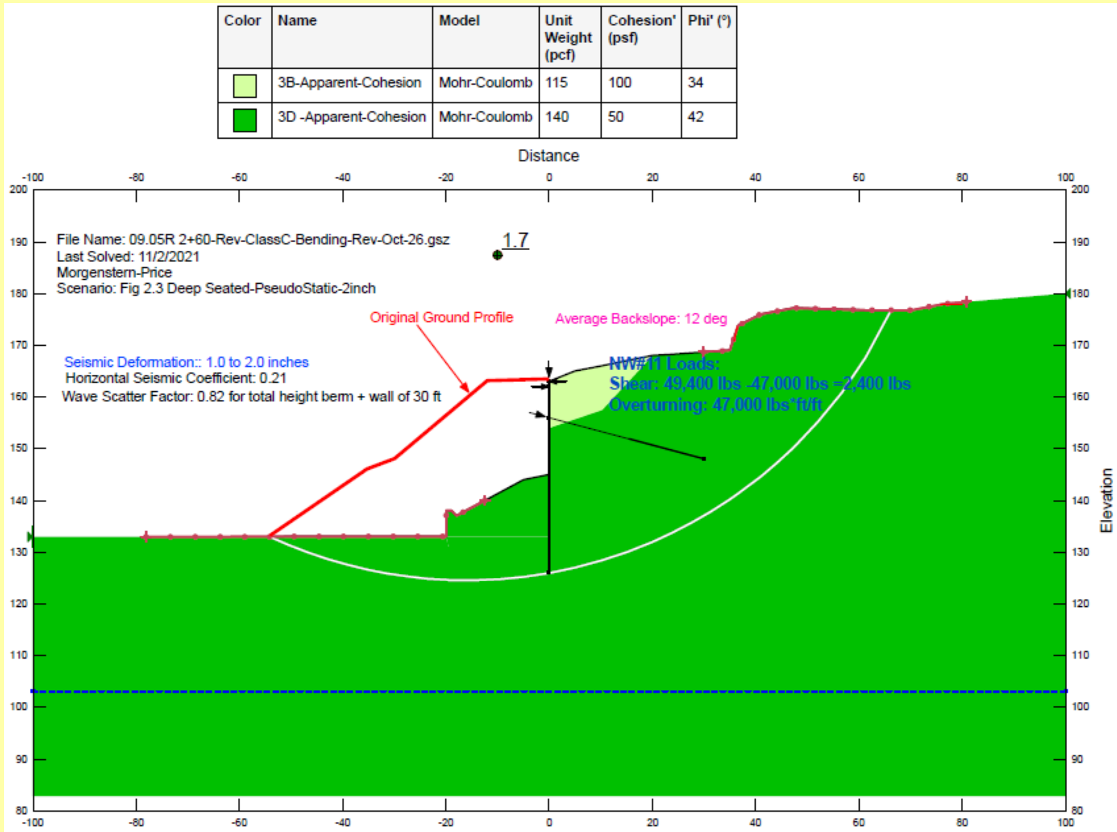
NOTES:

1. Actual pile embedment may need to be increased for foundation bearing requirements for the Noise Wall 11.
2. Static Loads from NW11 at Strength Combination: net Factored Shear force of 500 lbs/ft and Factored Overturning Moment of 8,500 lbs*ft modelled by two complementary point loads of 8,500 lbs spaced at 1.0 ft distance.

Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	3B	Mohr-Coulomb	115	0	34
	3D	Mohr-Coulomb	140	0	42



Wall Project Arrangement. Long-Term Static global stability of the soil mass containing the wall structure. Static Loads from NW11 at strength combination: net Factored Shear force of 500 lbs/ft and Factored Overturning Moment of 8,500 lbs*ft modelled by two complementary point loads of 8,500 lbs spaced at 1.0 ft distance.

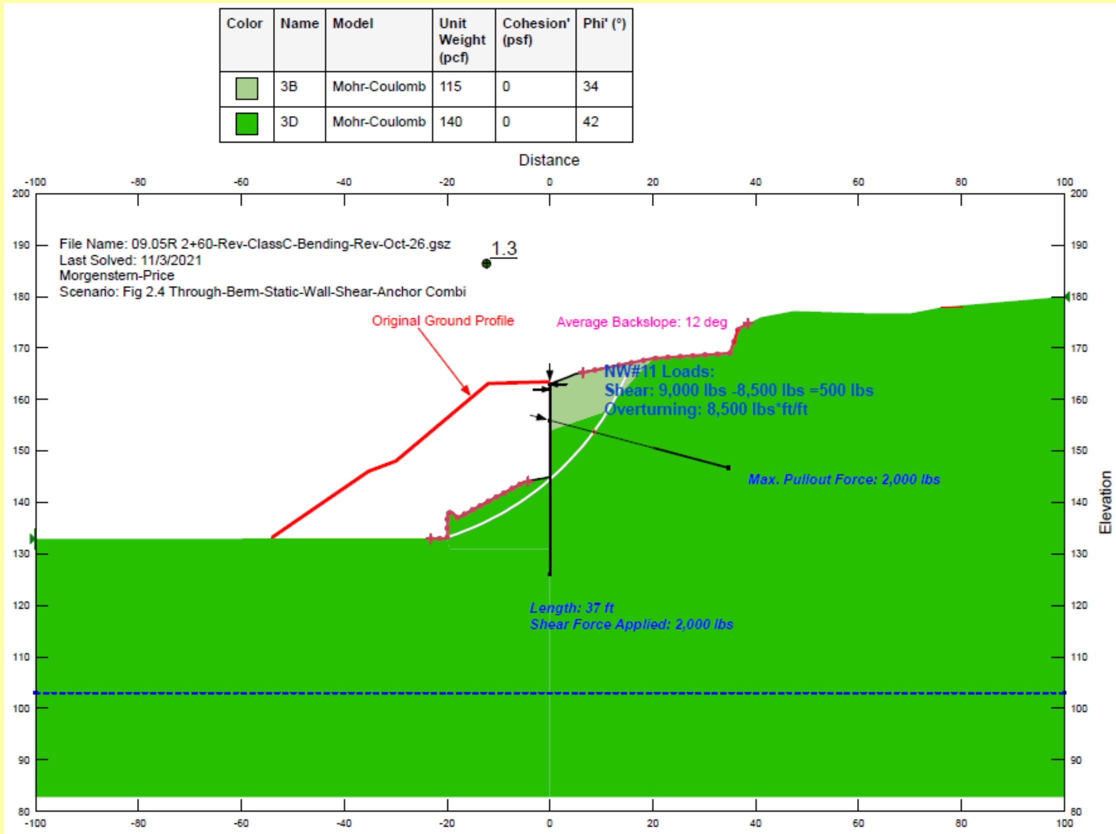


Project Arrangement. Pseudo- Static Global Stability of Soil mass containing the wall structure

NOTES:

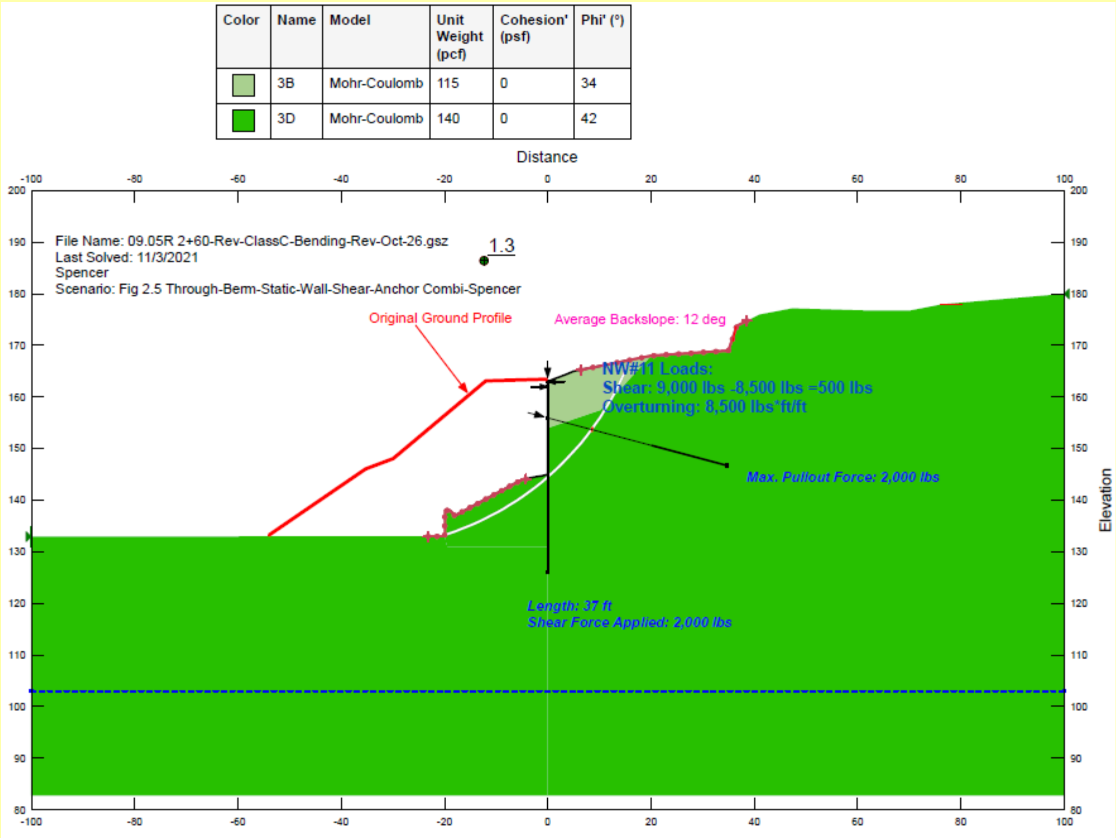
a) Net Factored Shear force of 2,400 lbs/ft and overturning moment of 47,000 lbs*ft/ft modelled by complementary point loads of 47,000 lbs spaced at 1.0 distance were included at the top of retaining wall / base of noise wall) to account for the seismic loads from Noise Wall 11 sitting on top of the soldier pile wall.

b) For the calculation of the seismic coefficient, k_h=0.21 (including wave scatter factor of 0.82), a 1.0 to 2.0 inch seismic deformation was assumed for the entire soil mass containing the slope and wall.

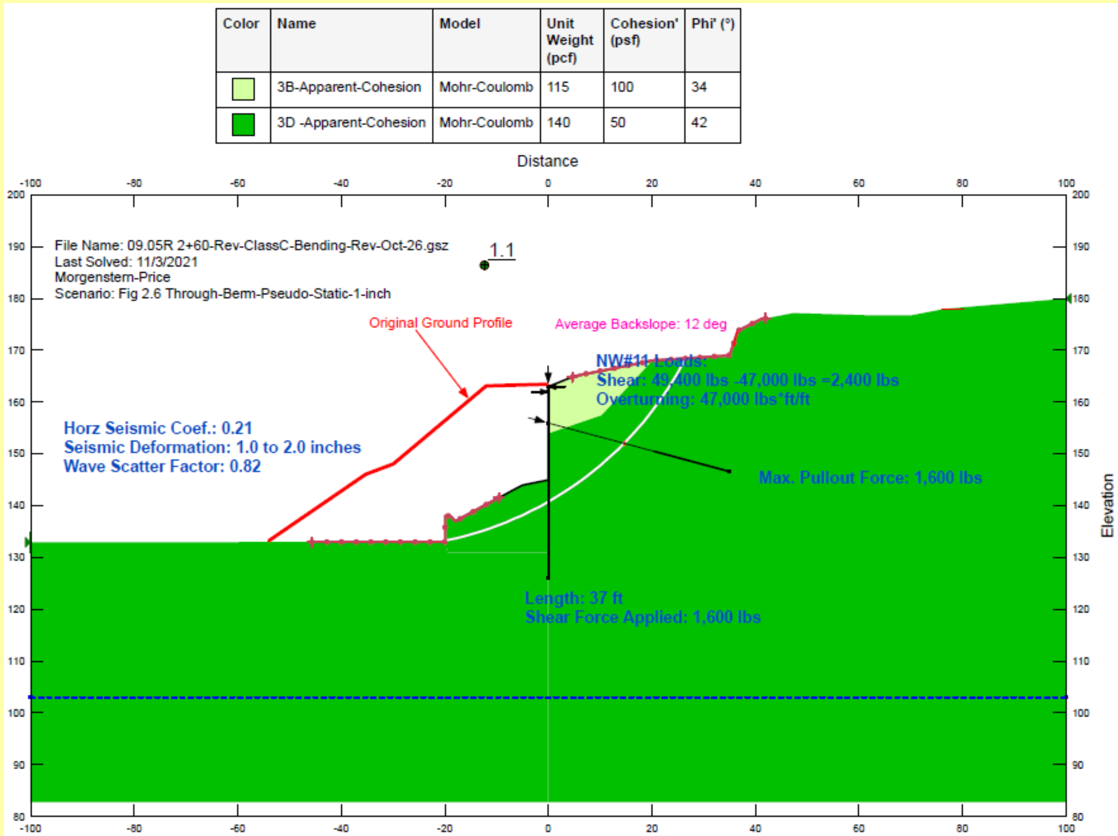


Project Arrangement. Static with NW11 loads at Strength combination. Failure mode through wall assuming a selected combination of shaft shear resistance and anchor pullout resistance. The analysis indicates that the wall shear and anchor pullout resistances must be at least 2,000 lbs/foot of wall to meet the static stability Fs=1.3.

OF NOTE: There are other multiple combinations of shaft and anchor resistances. The actual combination should be determined in consideration of all loading cases and scenarios for wall 9.05R-A, static and seismic, wall earth pressure envelopes, and including the forward compatibility cases.



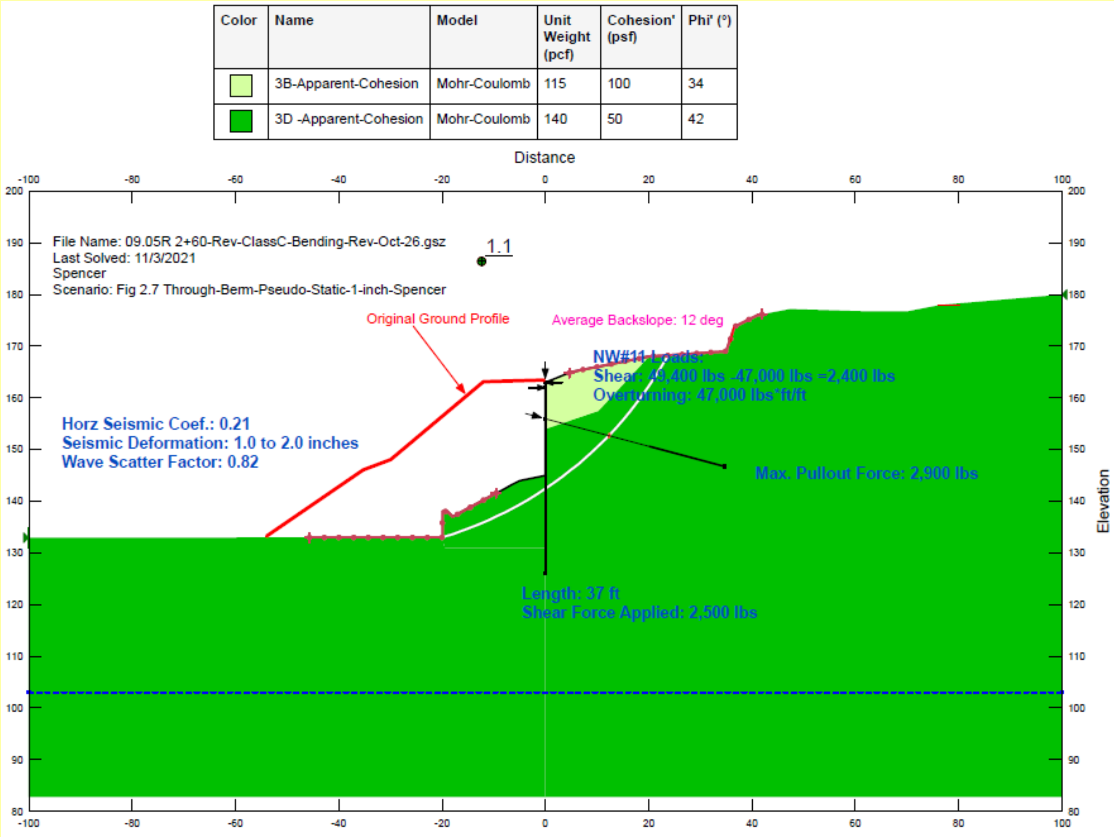
As above (Fig. E-2.4, Static- through wall & foreslope failure mode) - Spencer method. No differences from Morgenstern-Price



Project Arrangement. Extreme 1 (Seismic) – PSEUDO-STATIC SLOPE-WALL MODEL - Through wall and foreslope failure mode. M-P Method

NOTES:

a) The seismic coefficient k=0.21 (including Wave scatter factor of 0.82) determined for assumed 1.0 to 2.0 inch seismic movement;
b) Base seismic shear load and moment from NW#11 included (2,400 lbs/ft and 47,000 lbs*ft/ft for 24 ft tall NW)
c) The model indicates that one possible combination of structural resistance to meet the design specification of Fs=1.1 is identical with the static case shown in Fig. E-2.4 (wall shear resistance and anchor pullout resistance of at least 1,600 lbs/ft)
d) The model uses a nominal apparent cohesion for non-saturated cohesionless soils



As above (Fig.E-2.6) – Spencer method.

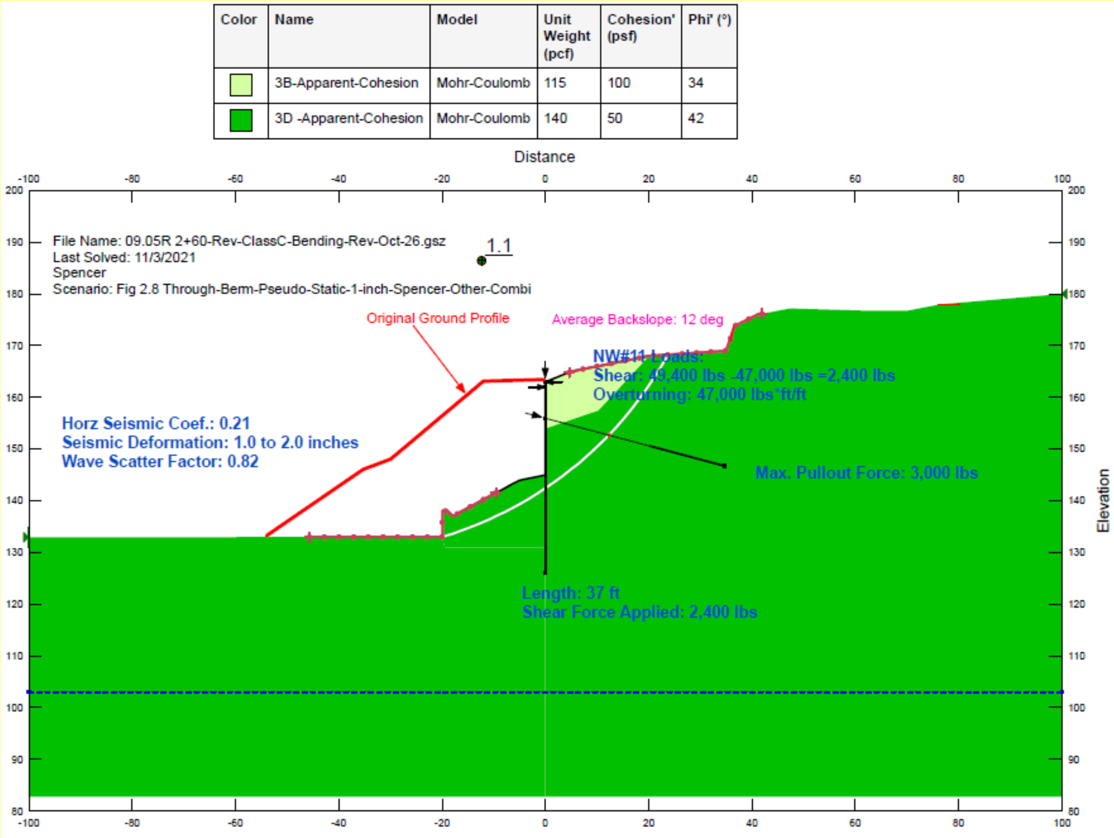
NOTES:

a) Compared to M-P method, the Spencer method demands for higher anchor pullout resistance (2,900 lbs/ft compared to 1,600 psf/ft) and higher shaft shear resistance (2,500 lbs/ft compared to 1,600 lbs/ft).

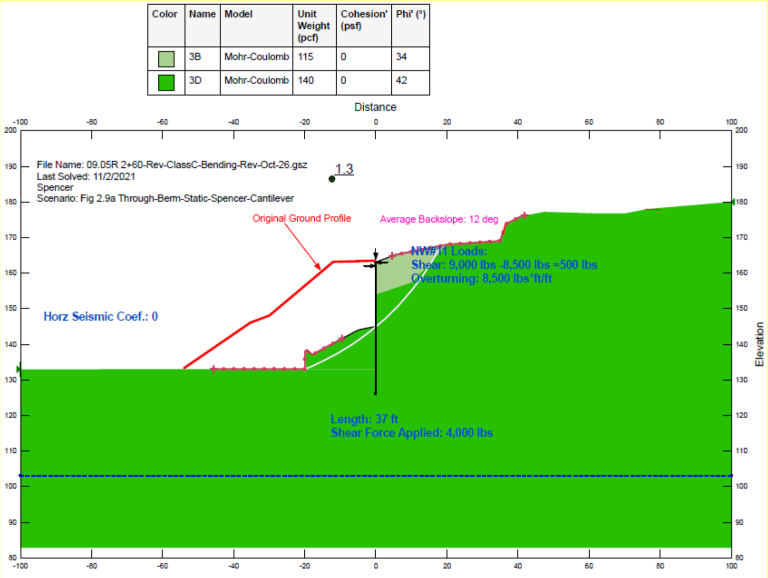
b) This failure mode and analysis method GOVERNS THE ANCHOR AND SHAFT DESIGN TO GLOBAL STABILITY and given wall arrangement.

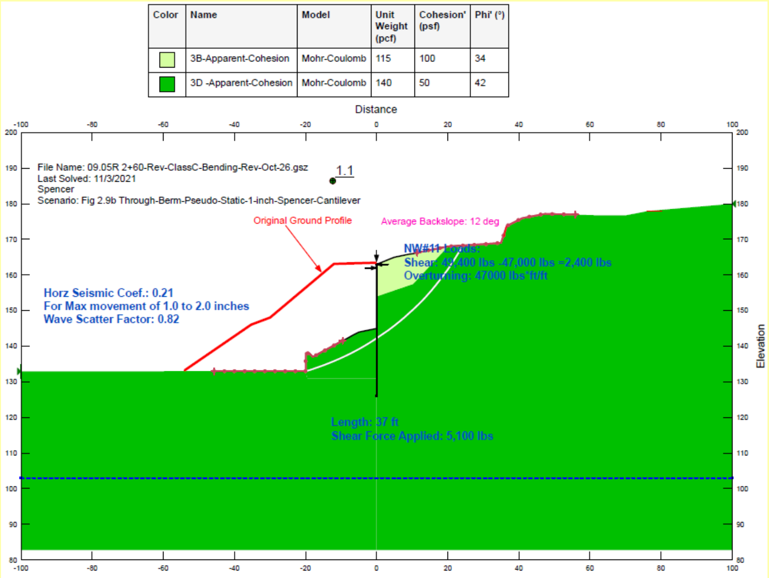
c) Other combinations of anchor and shaft resistances meeting the global stability requirement are also possible (example below in Figures E-2.8 and E-2.9)

d) Higher design structural stresses for the anchor and soldier pile shaft may occur from other structural design scenarios based on the earth-pressure models and the soil-structure and load-deformation design methods considered.



Same as above (Figure E-2.7) for illustration with a different combination of resisting designs: increased anchor resistance to 3,000 lbs instead of 2,900 lbs and decreased shaft resistance to 2,400 lbs instead of 2,500 lbs compared to structural combination in Fig. E-2.7.



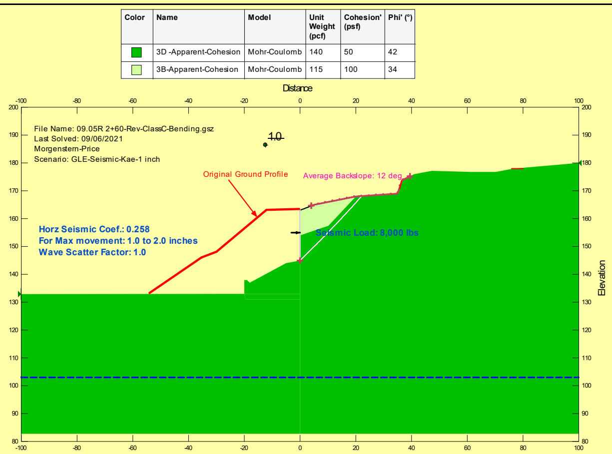


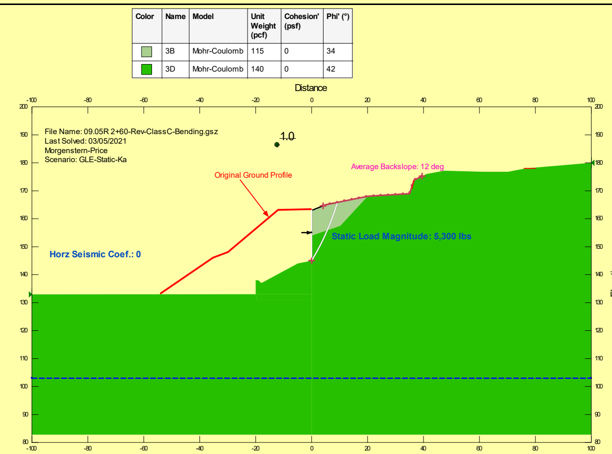
Same as above (Figure E2-8) for illustration purposes with a Cantilevered arrangement:

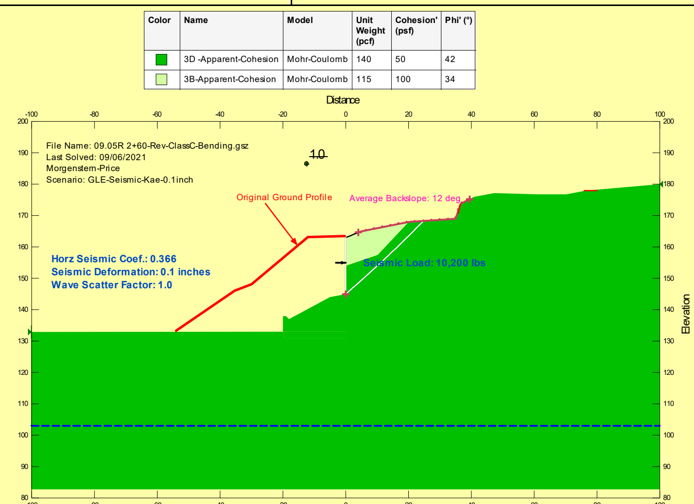
a) Static - Failure mode through wall and foreslope. The wall shear resistance must be at least 4,000 lbs/foot of wall to meet the static stability Fs=1.3.

b) Seismic: The wall shear resistance must be at least 5,100 lbs/foot of wall to meet the stability Fs=1.1. GOVERNS THE SHAFT DESIGN TO GLOBAL STABILITY and wall arrangement

Note: The cantilever option for exposed wall face exceeding 10 ft may not be practical for permanent structures due to potential for significant static deformation. Subject to acceptance of the wall deformation performance assessed by the structural design, the shaft embedment may need to be increased beyond the length shown herein subject to the shaft structural desing to lateral loads.







c)

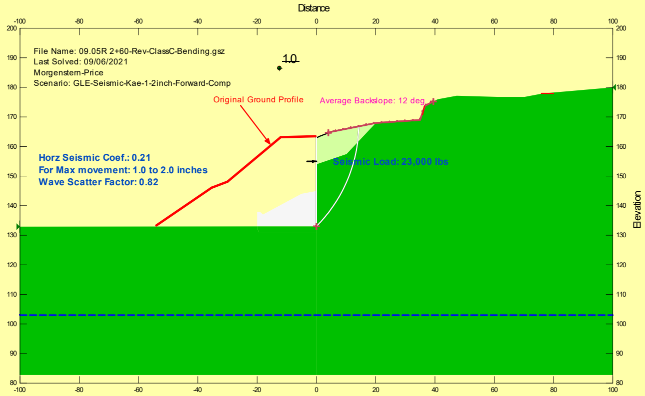
GLE based determination of Earth pressures on Walls

a) Pseudostatic seismic load on wall for 1.0 to 2.0 inch seismic displacement and Fs=1 resulted 8,000 lbs/ft. Accordingly, the equivalent seismic horizontal earth pressure coefficient is: Kae = 2*8000/((140+115)/2*18*18)) = 0.39

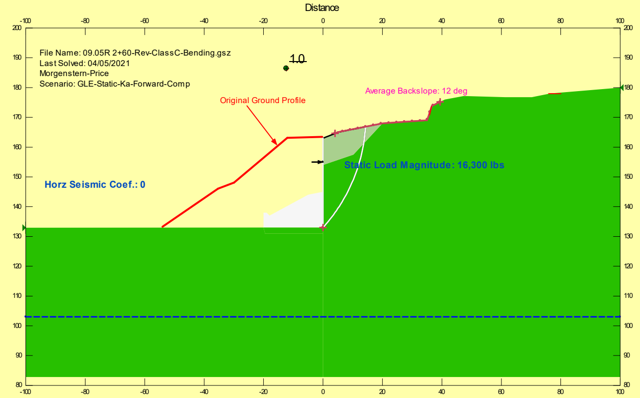
b) Static horizontal load on wall for Fs=1 resulted 5300 lbs/ft. Accordingly, the equivalent horizontal static earth pressure coefficient is:
Ka = 2*5300/((140+115)/2*18*18) = 0.26

c) Pseudostatic seismic load on wall for restrained seismic displacement of 0.1 inches and Fs=1 resulted 10,200 lbs/ft. Accordingly, the equivalent seismic horizontal earth pressure coefficient is: Kae = 2*10,200/((140+115)/2*18*18)) = 0.49

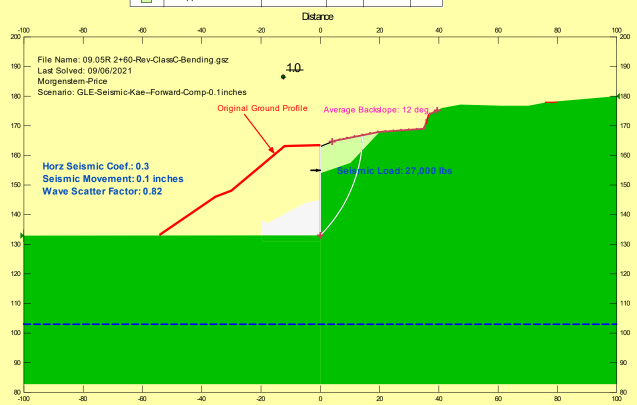
Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	3D -Apparent-Cohesion	Mohr-Coulomb	140	50	42
	3B-Apparent-Cohesion	Mohr-Coulomb	115	100	34



Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	3B	Mohr-Coulomb	115	0	34
	3D	Mohr-Coulomb	140	0	42



Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)
	3D -Apparent-Cohesion	Mohr-Coulomb	140	50	42
	3B-Apparent-Cohesion	Mohr-Coulomb	115	100	34

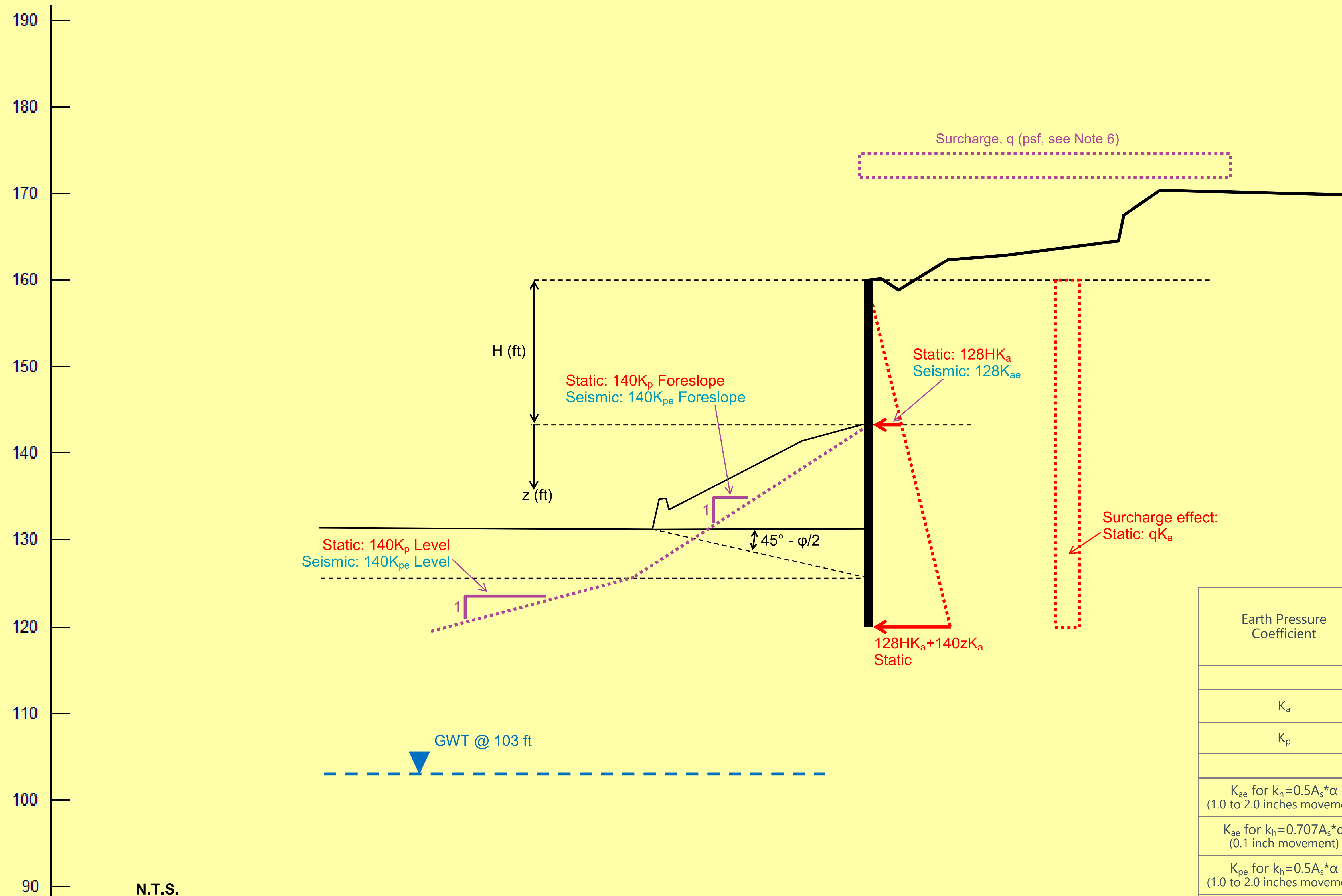


GLE based determination of Earth pressures on Walls at Forward Compatibility

a) Pseudostatic seismic load on wall for 1.0 to 2.0 inch seismic displacement and Fs=1 resulted 23,000 lbs/ft. Accordingly, the equivalent seismic horizontal earth pressure coefficient is: Kae = 2*23000/((2*140/3+115/3)*30*30) = 0.39

b) Static horizontal load on wall for Fs=1 resulted 16300 lbs/ft. Accordingly, the equivalent horizontal static earth pressure coefficient is: Ka=2*16300/((2*140/3+115/3)*30*30) = 0.27

c) Pseudostatic seismic load on wall for restrained seismic displacement of 0.1 inches and Fs=1 resulted 27,000 lbs/ft. Accordingly, the equivalent seismic horizontal earth pressure coefficient is: Kae = 2*27,000/((2*140/3+115/3)*30*30) = 0.46



NOTES:

1. This figure is based on WSDOT Dwg 8.1-A3-2.
2. For earth pressure loads on soldier piles spaced at more than 3 pile diameters, refer to AASHTO C11.8.6.3 (2017).
3. Loads from Noise Wall to be included as appropriate in the structural design of the shoring.
4. Seismic pressures apply above the toe finished grade only.
5. All parameters are unfactored.
6. Surcharge live load 'q' (psf) as applicable for static cases.
7. Providied the soils within the passive zone are undisturbed, the passive resistance is usually neglected within the upper 2.0 ft below grade for static cases. For seismic cases the passive resistance may be relied upon from the ground surface.
8. The structural design should interpolate between the provided seismic earth pressures to select the appropriate pressures consistent with the estimated seismic deformation.

Earth Pressure Coefficient	Level Ground	Average Backslope: 12° (Current Project)	Average Foreslope: 27° (Current Project)	Average Backslope: 12° (Forward Compatibility)
STATIC				
K_a	NA	0.26	NA	0.27
K_p	14.1	NA	2.7	NA
SEISMIC				
K_{ae} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	NA	0.39	NA	0.39
K_{ae} for k_h=0.707A_s*α (0.1 inch movement)	NA	0.49	NA	0.46
K_{pe} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	10.0	NA	1.9	NA
K_{pe} for k_h=0.707A_s*α (0.1 inch movement)	9.4	NA	1.8	NA

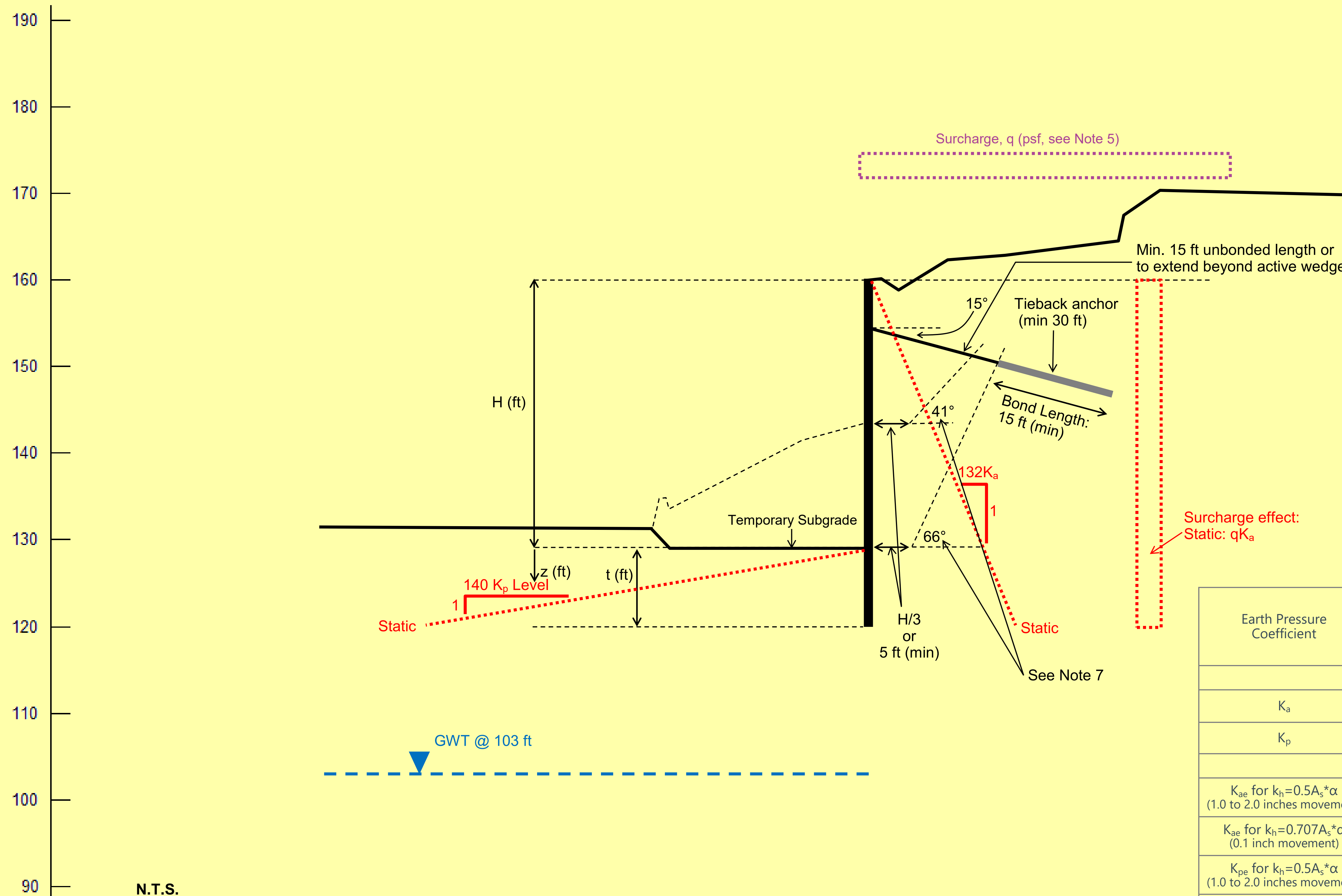
For additional details see Section 6.2 and Table 8 in the report text.

Figure E-2.12: 09.05R-A

Apparent Earth Pressures (Cantilever Section, Project Wall Height)

FLATIRON LANE

wood.



NOTES:

1. This figure is based on WSDOT Dwg 8.1-A3-2.
2. For earth pressure loads on soldier piles spaced at more than 3 pile diameters, refer to AASHTO C11.8.6.3 (2017).
3. Loads from Noise Wall to be included as appropriate in the structural design of the shoring.
4. All parameters are unfactored.
5. Surcharge live load 'q' (psf) as applicable for static cases.
6. Provided the soils within the passive zone are undisturbed, the passive resistance is usually neglected within the upper 2.0 ft below grade for static cases. For seismic cases the passive resistance may be relied upon from the ground surface.
7. Bond location behind the wall shall be the greater of the limits resulting from the two geometric constructions shown at 66 degrees from the lowest cut grade and 41 degrees from top of foreslope.

Earth Pressure Coefficient	Level Ground	Average Backslope: 12° (Current Project)	Average Foreslope: 27° (Current Project)	Average Backslope: 12° (Forward Compatibility)
STATIC				
K_a	NA	0.26	NA	0.27
K_p	14.1	NA	2.7	NA
SEISMIC				
K_{ae} for $k_h=0.5A_s*\alpha$ (1.0 to 2.0 inches movement)	NA	0.39	NA	0.39
K_{ae} for $k_h=0.707A_s*\alpha$ (0.1 inch movement)	NA	0.49	NA	0.46
K_{pe} for $k_h=0.5A_s*\alpha$ (1.0 to 2.0 inches movement)	10.0	NA	1.9	NA
K_{pe} for $k_h=0.707A_s*\alpha$ (0.1 inch movement)	9.4	NA	1.8	NA

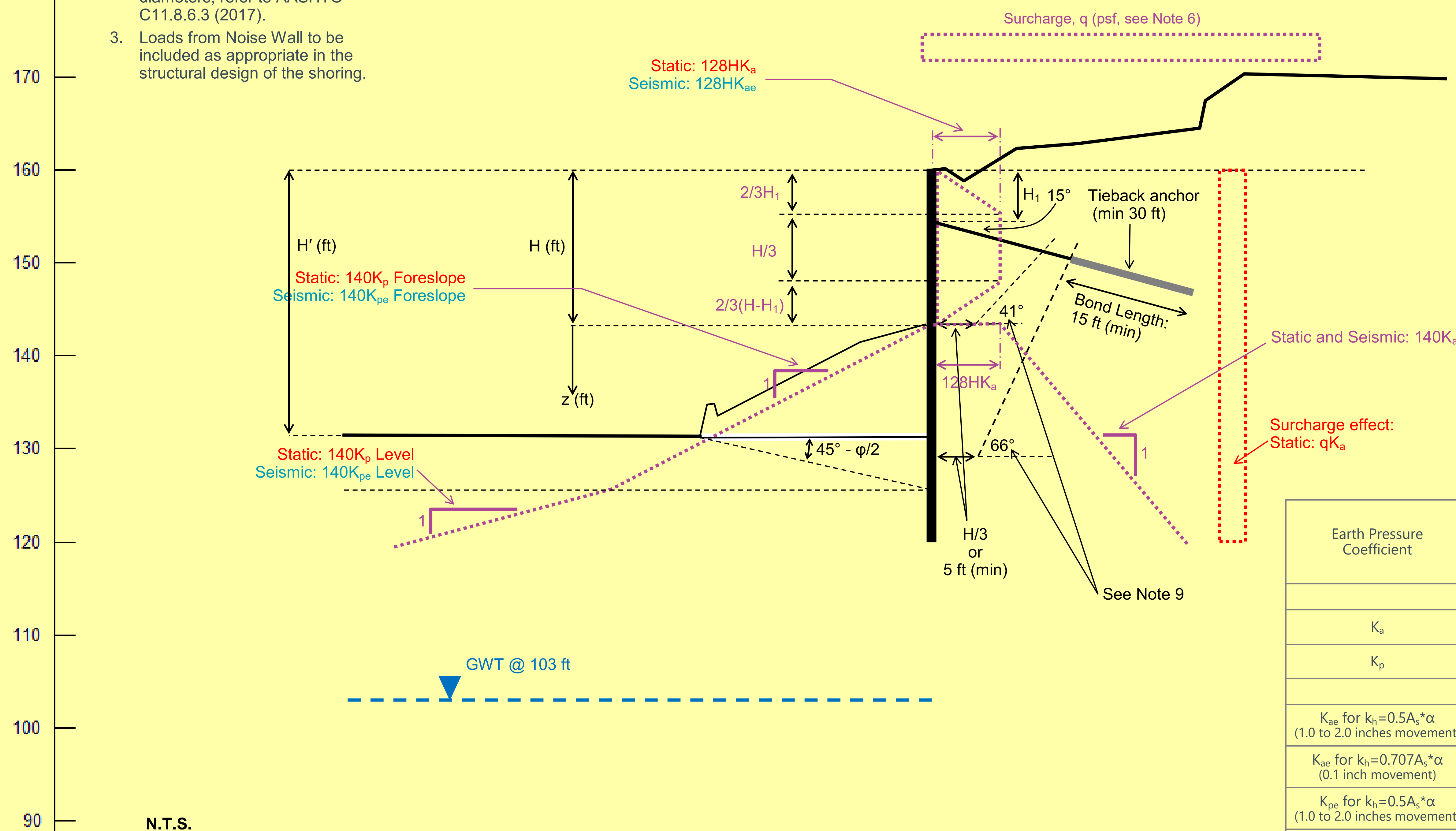
For additional details see Section 6.2 and Table 8 in the report text.

Figure E-2.13: **09.05R-A**

Apparent Earth Pressures
Single Anchor
(During Construction)

NOTES:

1. This figure is based on WSDOT Dwg 8.1-A3-2.
2. For earth pressure loads on soldier piles spaced at more than 3 pile diameters, refer to AASHTO C11.8.6.3 (2017).
3. Loads from Noise Wall to be included as appropriate in the structural design of the shoring.



NOTES (cont'd):

4. Additional seismic pressures apply above the toe finished grade only.
5. All parameters are unfactored.
6. Surcharge live load 'q' (psf) as applicable for static cases.
7. Provided the soils within the passive zone are undisturbed, the passive resistance is usually neglected within the upper 2.0 ft below grade for static cases. For seismic cases the passive resistance may be relied upon from the ground surface.
8. The structural design should interpolate between the provided seismic earth pressures to select the appropriate pressures consistent with the estimated seismic deformation.
9. Bond location behind the wall shall be the greater of the limits resulting from the two geometric constructions shown at 66 degrees from the lowest cut grade and 41 degrees from top of foreslope.

Earth Pressure Coefficient	Level Ground	Average Backslope: 12° (Current Project)	Average Foreslope: 27° (Current Project)	Average Backslope: 12° (Forward Compatibility)
STATIC				
K_a	NA	0.26	NA	0.27
K_p	14.1	NA	2.7	NA
SEISMIC				
K_{ae} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	NA	0.39	NA	0.39
K_{ae} for k_h=0.707A_s*α (0.1 inch movement)	NA	0.49	NA	0.46
K_{pe} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	10.0	NA	1.9	NA
K_{pe} for k_h=0.707A_s*α (0.1 inch movement)	9.4	NA	1.8	NA

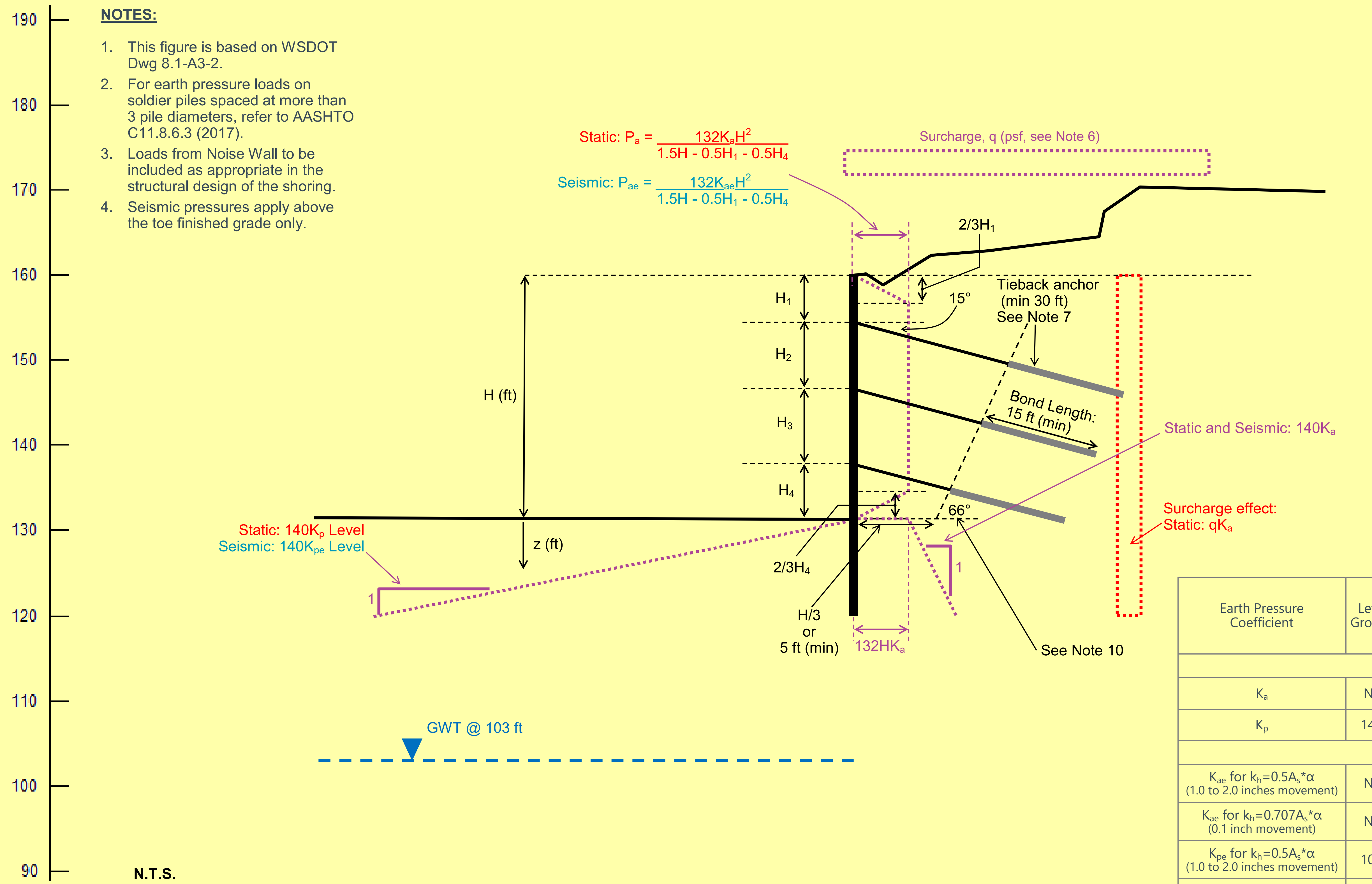
For additional details see Section 6.2 and Table 8 in the report text.

Figure E-2.14: 09.05R-A

Apparent Earth Pressures (Single Anchor with Berm, Project Wall Height)

NOTES:

1. This figure is based on WSDOT Dwg 8.1-A3-2.
2. For earth pressure loads on soldier piles spaced at more than 3 pile diameters, refer to AASHTO C11.8.6.3 (2017).
3. Loads from Noise Wall to be included as appropriate in the structural design of the shoring.
4. Seismic pressures apply above the toe finished grade only.



NOTES (cont'd):

5. All parameters are unfactored.
6. Surcharge live load 'q' (psf) as applicable for static cases.
7. Anchors shown are for conceptual and illustrative purposes only and do not represent suggested design.
8. Provided the soils within the passive zone are undisturbed, the passive resistance is usually neglected within the upper 2.0 ft below grade for static cases. For seismic cases the passive resistance may be relied upon from the ground surface.
9. The structural design should interpolate between the provided seismic earth pressures to select the appropriate pressures consistent with the estimated seismic deformation.
10. Bond location behind the wall shall be the greater between the distance determined for the current project arrangement and the geometric construction shown at 66 degrees from the lowest cut grade.

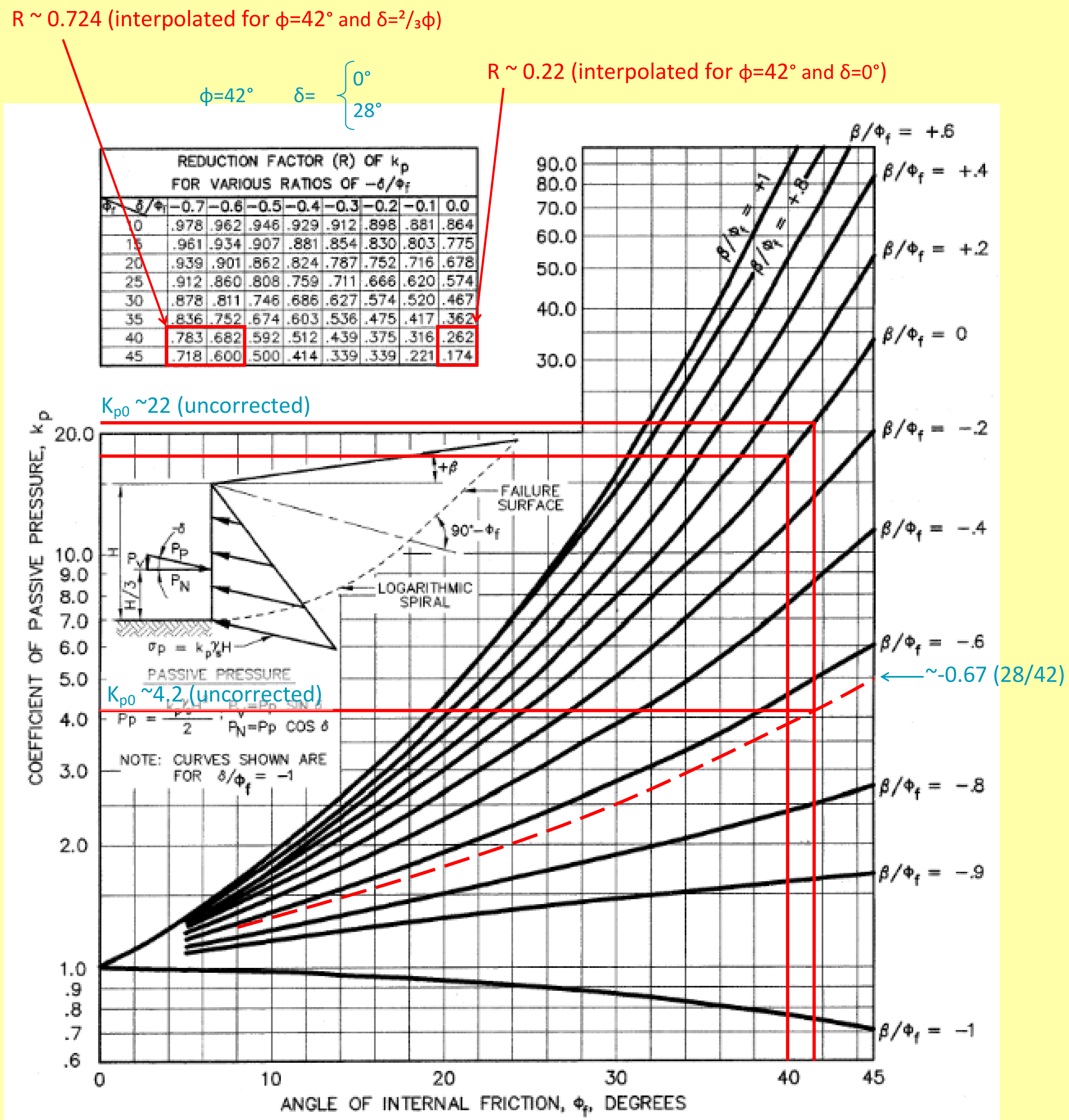
Earth Pressure Coefficient	Level Ground	Average Backslope: 12° (Current Project)	Average Foreslope: 27° (Current Project)	Average Backslope: 12° (Forward Compatibility)
STATIC				
K_a	NA	0.26	NA	0.27
K_p	14.1	NA	2.7	NA
SEISMIC				
K_{ae} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	NA	0.39	NA	0.39
K_{ae} for k_h=0.707A_s*α (0.1 inch movement)	NA	0.49	NA	0.46
K_{pe} for k_h=0.5A_s*α (1.0 to 2.0 inches movement)	10.0	NA	1.9	NA
K_{pe} for k_h=0.707A_s*α (0.1 inch movement)	9.4	NA	1.8	NA

For additional details see Section 6.2 and Table 8 in the report text.

Figure E-2.15: **09.05R-A**

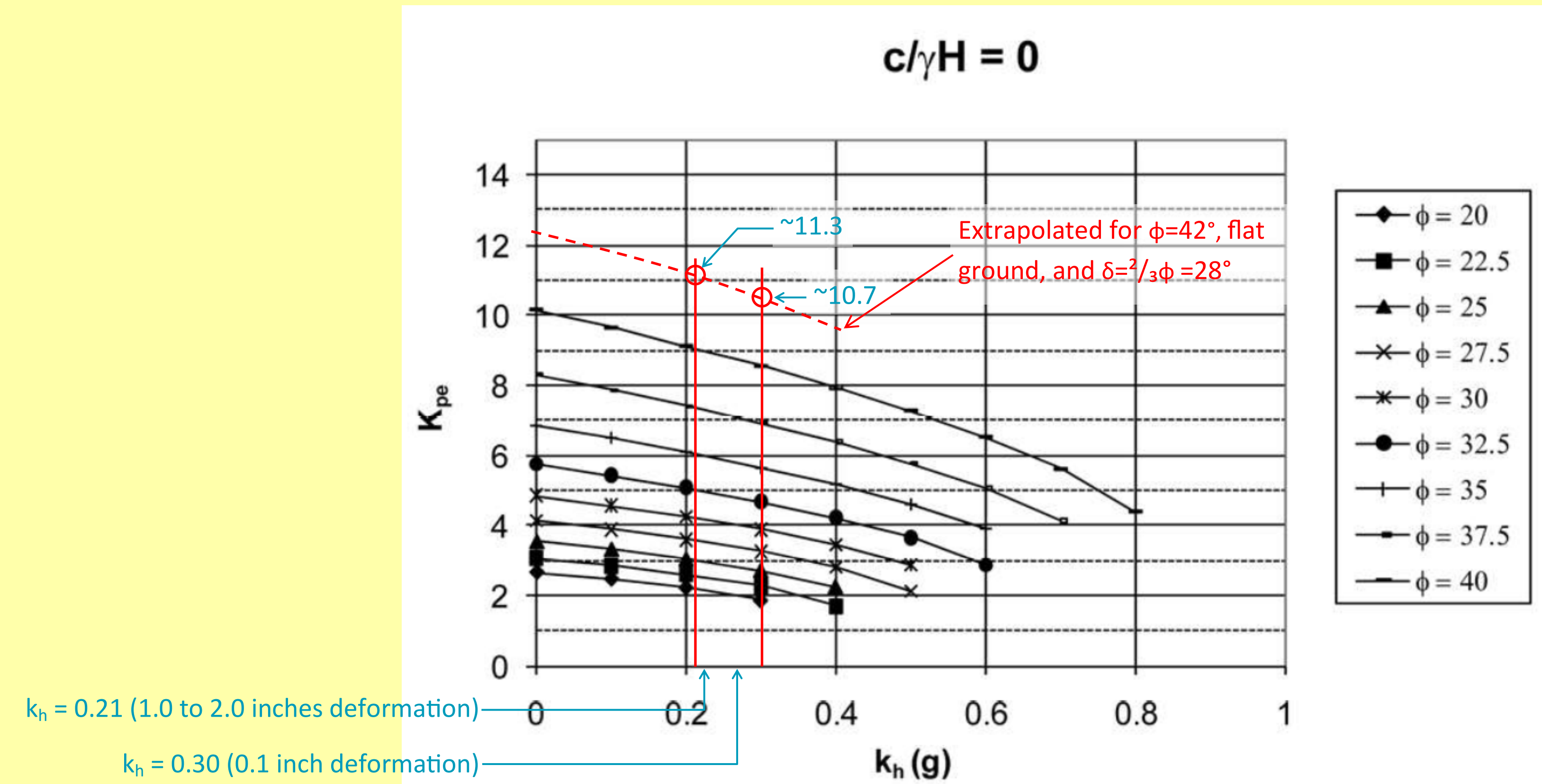
Apparent Earth Pressures (Multiple Anchors, Forward Compatibility Height)

FLATIRON LANE wood.



REDUCTION FACTOR (R) OF k_p FOR VARIOUS RATIOS OF $-\delta/\phi_f$								
ϕ_f \ δ/ϕ_f	−0.7	−0.6	−0.5	−0.4	−0.3	−0.2	−0.1	0.0
10	.978	.962	.946	.929	.912	.898	.881	.864
15	.961	.934	.907	.881	.854	.830	.803	.775
20	.939	.901	.862	.824	.787	.752	.716	.678
25	.912	.860	.808	.759	.711	.666	.620	.574
30	.878	.811	.746	.686	.627	.574	.520	.467
35	.836	.752	.674	.603	.536	.475	.417	.362
40	.783	.682	.592	.512	.439	.375	.316	.262
45	.718	.600	.500	.414	.339	.339	.221	.174

Fig.3.11.5.4-2 AASHTO 2017



Excerpt from Fig. A11.4-2 AASHTO 2017 for flat ground

Total/Unprojected Passive Coefficient for $\delta = {}^2/_3\phi$

Figure E-2.16: 09.05R-A

Apparent Earth Pressures

(Earth Pressure Coefficient Calculations)

FLATIRON LANE

wood.

In Association with

Appendix E-3
Calculation of Drilled Shaft Side Resistance

Input Parameters applicable for ESU 3D (see Table 8 in report text)			
Soil Unit Weight	γ	140	pcf
Concrete Unit Weight	γ_{Conc}	145	pcf
Soil Effective Friction Angle[1]	φ'_f	45	degrees
Corrected SPT Blow Count	$(N_1)_{60}$	80	blows per foot
Atmospheric Pressure	p_a	2.12	ksf
Preconsolidation stress	σ'p	33.2	ksf
Cut off Depth	d_C	7.5	ft
Concrete Stick Up (above finished grade)	d_S	0	ft

Embedment Range (ft)	Mid-Depth, d_{mid} (ft)	Vertical Effective Stress at Soil Mid Layer, σ'_v [2] (psf)	Load Transfer Coefficient, β [3]	q_s [5] (psf)	q_s Max [6] (psf)	q_s Design [7]
0 to 7.5	3.75	525	5.50 [4]	2885	545	545
7.5 to 10	8.75	1225	3.02	3699	1270	1270
10 to 15	12.5	1750	2.35	4105	1815	1815
15 to 20	17.5	2450	1.85	4530	2540	2540

NOTES:

1. Effective soil friction angle as per 10.8.3.5.2B-3 from AASHTO 2017

$$\varphi'_f = 27.5 + 9.2\log\left[(N_1)_{60}\right]$$

2. Vertical effective stress at soil mid layer

$$\sigma'_v = d_{mid}\,\gamma$$

3. Load transfer coefficient as per 10.8.3.5.2b-2 from AASHTO 2017

$$\beta = (1 - sin\varphi'_f)\left(\frac{\sigma'_p}{\sigma'_v}\right)^{sin\varphi'_f} tan\varphi'_f$$

4. Where embedment depth is less than or equal to cut off depth as per Art. 13.3.5.1, FHWA GEC 010, 2010

$$\beta = (1 - sin\varphi'_f)\left(\frac{\sigma'_p}{\gamma \cdot d_c}\right)^{sin\varphi'_f} tan\varphi'_f$$

5. Effective vertical preconsolidation stress, σ'_p, as per 10.8.3.5.2b-4 from AASHTO 2017, where m = 0.8 for silty sands to sandy silts

$$\frac{\sigma'_p}{p_a} = 0.47(N_{60})^m$$

6. Unit side resistance as per 10.8.3.5.2b-1 from AASHTO 2017

$$q_s = \beta \cdot \sigma'_v$$

7. Maximum unit side resistance (based on the maximum possible soil-concrete interface effective horizontal stress)

$$q_{sMax} = \gamma_{Conc}\,(d_{mid} + d_S)\,\tan\varphi'_f$$

8. Design unit side resistance—lesser of q_s and q_{sMax}

Prepared by: NGould
Reviewed by: DDimitriu

Figure E-3.1: **09.05R-A**

Calculation of Drilled Shaft Side Resistance for ESU3D

FLATIRON LANE

wood.

EXAMPLE CALCULATION FOR EMBEDMENT DEPTH OF 7.5 to 10 ft:

Effective soil friction angle	$\varphi'_f = 27.5 + 9.2\log\left[(N_1)_{60}\right]$	$\varphi'_f = 27.5 + 9.2\log[80] = 45\,°$
Vertical effective stress at soil mid layer	$\sigma'_v = d_{mid}\,\gamma$	$\sigma'_v = 8.75\,ft \times 140\,pcf = 1225\,psf$
Effective vertical preconsolidation stress	$\frac{\sigma'_p}{p_a} = 0.47(N_{60})^m$	$\sigma'_p = 2.12 \times 0.47(80)^{0.8} = 33.2\,ksf$
Load transfer coefficient	$\beta = (1 - sin\varphi'_f)\left(\frac{\sigma'_p}{\sigma'_v}\right)^{sin\varphi'_f} tan\varphi'_f$	$\beta = (1 - sin\,45°)\left(\frac{33.2\,ksf \times 1000}{1225\,psf}\right)^{sin\,45°} \times \tan 45° = 3.02$
Unit side resistance	$q_s = \beta \cdot \sigma'_v$	$q_s = 3.02 \times 1225\,psf = 3699\,psf$
Maximum unit side resistance	$q_{sMax} = \gamma_{Conc}\,(d_{mid} + d_S)\,\tan\varphi'_f$	$q_{sMax} = 145\,pcf\,(8.75\,ft + 0\,ft)\,\tan 45° = 1270\,psf$
Design unit side resistance	$q_s \le q_{sMax}$	$q_s > q_{sMax} \therefore q_{sDesign} = q_{sMax} = 1270\,psf$

Prepared by: NGould
Reviewed by: DDimitriu

Figure E-3.2: **09.05R-A**

Calculation of Drilled Shaft Side Resistance for ESU3D

FLATIRON LANE

wood.

In Association with

Appendix E-4
SlopeW Input & Output Files

Fig 2.1 Static-Temporary-Forward-Compat-Global

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 676
Date: 11/2/2021
Time: 11:17:01 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.1 Static-Temporary-Forward-Compat-Global

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 0 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3D

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 0 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-55.15, 132.97806) ft
Left-Zone Right Coordinate: (-11.05, 131) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (9.1, 165.82) ft
Right-Zone Right Coordinate: (69.3, 176.8) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-15.2, 185.9) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (34.67929, 146.70771) ft
Length: 35.902643 ft
Direction: 165 °
F of S Dependent: No
Pullout Resistance: 7,900 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 0 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 12,409.291 lbs/ft
Max. Pullout Force: 0 lbs
Shear Force Applied: 0 lbs
Factored Tensile Capacity: 0 lbs

Reinforcement 2

Type: Pile

Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 20,000 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Parallel to Slip

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	9,000	0
Point Load 2	(0, 162)	8,500	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2		19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4		14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Fig 2.2 Deep-Seated Static-Long-Term

File Information

- File Version: 8.16
- Title: 09.05R 2+70
- Created By: Nunes, Miguel
- Last Edited By: Gould, Nicole
- Revision Number: 676
- Date: 11/2/2021
- Time: 11:17:01 AM
- Tool Version: 8.16.5.15361
- File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
- Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

- Length(L) Units: Feet
- Time(t) Units: Seconds
- Force(F) Units: Pounds
- Pressure(p) Units: psf
- Strength Units: psf
- Unit Weight of Water: 62.4 pcf
- View: 2D
- Element Thickness: 1

Analysis Settings

Fig 2.2 Deep-Seated Static-Long-Term

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 0 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3D

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 0 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-55.15, 132.97806) ft
Left-Zone Right Coordinate: (-15.11674, 138.55252) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (9.1, 165.82) ft
Right-Zone Right Coordinate: (69.3, 176.8) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-15.2, 185.9) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft
Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (34.67929, 146.70771) ft
Length: 35.902643 ft
Direction: 165 °
F of S Dependent: No
Pullout Resistance: 7,900 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 0 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 12,409.291 lbs/ft
Max. Pullout Force: 0 lbs
Shear Force Applied: 0 lbs
Factored Tensile Capacity: 0 lbs

Reinforcement 2

Type: Pile

Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 20,000 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Parallel to Slip

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	9,000	0
Point Load 2	(0, 162)	8,500	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D	19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Fig 2.3 Deep Seated-PseudoStatic-2inch

File Information

- File Version: 8.16
- Title: 09.05R 2+70
- Created By: Nunes, Miguel
- Last Edited By: Gould, Nicole
- Revision Number: 676
- Date: 11/2/2021
- Time: 11:17:01 AM
- Tool Version: 8.16.5.15361
- File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
- Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

- Length(L) Units: Feet
- Time(t) Units: Seconds
- Force(F) Units: Pounds
- Pressure(p) Units: psf
- Strength Units: psf
- Unit Weight of Water: 62.4 pcf
- View: 2D
- Element Thickness: 1

Analysis Settings

Fig 2.3 Deep Seated-PseudoStatic-2inch

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 50 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 100 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-78.15, 132.9637) ft
Left-Zone Right Coordinate: (-12.45874, 139.98376) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (29.87824, 168.65855) ft
Right-Zone Right Coordinate: (80.85, 178.36943) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-10, 187.45) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft
Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.21

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (30, 148) ft
Length: 31.048349 ft
Direction: 165.07 °
F of S Dependent: No
Pullout Resistance: 7,900 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 10,000 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 12,409.291 lbs/ft
Max. Pullout Force: 10,000 lbs

Shear Force Applied: 0 lbs
Factored Tensile Capacity: 10,000 lbs

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 30,000 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	49,400	0
Point Load 2	(0, 162)	47,000	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131

Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Fig 2.4 Through-Berm-Static-Wall-Shear-Anchor Combi

File Information

- File Version: 8.16
- Title: 09.05R 2+70
- Created By: Nunes, Miguel
- Last Edited By: Gould, Nicole
- Revision Number: 708
- Date: 11/3/2021
- Time: 6:43:07 AM
- Tool Version: 8.16.5.15361
- File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
- Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

- Length(L) Units: Feet
- Time(t) Units: Seconds
- Force(F) Units: Pounds
- Pressure(p) Units: psf
- Strength Units: psf
- Unit Weight of Water: 62.4 pcf
- View: 2D
- Element Thickness: 1

Analysis Settings

Fig 2.4 Through-Berm-Static-Wall-Shear-Anchor Combi

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit

Critical slip surfaces saved: 1
Resisting Side Maximum Convex Angle: 1 °
Driving Side Maximum Convex Angle: 5 °
Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 0 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3D

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 0 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-23.2, 132.998) ft
Left-Zone Right Coordinate: (-4.27228, 144.14554) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (6.36433, 165.27287) ft
Right-Zone Right Coordinate: (38.49192, 174.74596) ft
Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft
Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (34.67929, 146.70771) ft
Length: 35.902643 ft
Direction: 165 °
F of S Dependent: No
Pullout Resistance: 7,000 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 2,000 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 10,995.574 lbs/ft
Max. Pullout Force: 2,000 lbs
Shear Force Applied: 0 lbs
Factored Tensile Capacity: 2,000 lbs

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 2,000 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	9,000	0
Point Load 2	(0, 162)	8,500	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146

Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft^2)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D	19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Fig 2.5 Through-Berm-Static-Wall-Shear-Anchor Combi-Spencer

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 708
Date: 11/3/2021
Time: 6:43:07 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.5 Through-Berm-Static-Wall-Shear-Anchor Combi-Spencer

Kind: SLOPE/W
Method: Spencer
Settings
  PWP Conditions Source: Piezometric Line
  Apply Phreatic Correction: No
  Use Staged Rapid Drawdown: No
Slip Surface
  Direction of movement: Right to Left
  Use Passive Mode: No
  Slip Surface Option: Entry and Exit
  Critical slip surfaces saved: 1
  Resisting Side Maximum Convex Angle: 1 °

Driving Side Maximum Convex Angle: 5 °
Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 0 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3D

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 0 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-23.2, 132.998) ft
Left-Zone Right Coordinate: (-4.27228, 144.14554) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (6.36433, 165.27287) ft
Right-Zone Right Coordinate: (38.49192, 174.74596) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Reinforcements

Reinforcement 1

Type: Anchor

Outside Point: (0, 156) ft

Inside Point: (34.67929, 146.70771) ft

Length: 35.902643 ft

Direction: 165 °

F of S Dependent: No

Pullout Resistance: 7,000 psf

Resistance Reduction Factor: 1

Bond Length: 15 ft

Bond Diameter: 0.5 ft

Anchor Spacing: 1 ft

Force Distribution: Distributed

Anchorage: Yes

Tensile Capacity: 2,000 lbs

Reduction Factor: 1

Shear Force: 0 lbs

Shear Reduction Factor: 1

Shear Option: Parallel to Slip

Factored Pullout Resistance: 10,995.574 lbs/ft

Max. Pullout Force: 2,000 lbs

Shear Force Applied: 0 lbs

Factored Tensile Capacity: 2,000 lbs

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 2,000 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	9,000	0
Point Load 2	(0, 162)	8,500	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163

Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D	19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Fig 2.6 Through-Berm-Pseudo-Static-1-inch

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 709
Date: 11/3/2021
Time: 6:55:54 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.6 Through-Berm-Pseudo-Static-1-inch

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 50 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 100 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-45.65, 132.98399) ft
Left-Zone Right Coordinate: (-9.53096, 141.56025) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (4.57018, 164.82807) ft
Right-Zone Right Coordinate: (41.9377, 176.1772) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.21

Reinforcements

Reinforcement 1

Type: Anchor

Outside Point: (0, 156) ft

Inside Point: (34.99857, 146.62216) ft

Length: 36.233186 ft

Direction: 165 °

F of S Dependent: No

Pullout Resistance: 7,900 psf

Resistance Reduction Factor: 1

Bond Length: 15 ft

Bond Diameter: 0.5 ft

Anchor Spacing: 1 ft

Force Distribution: Distributed

Anchorage: Yes

Tensile Capacity: 1,600 lbs

Reduction Factor: 1

Shear Force: 0 lbs

Shear Reduction Factor: 1

Shear Option: Parallel to Slip

Factored Pullout Resistance: 12,409.291 lbs/ft

Max. Pullout Force: 1,600 lbs

Shear Force Applied: 0 lbs
Factored Tensile Capacity: 1,600 lbs

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 1,600 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	49,400	0
Point Load 2	(0, 162)	47,000	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131

Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft^2)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Fig 2.7 Through-Berm-Pseudo-Static-1-inch-Spencer

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 709
Date: 11/3/2021
Time: 6:55:54 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.7 Through-Berm-Pseudo-Static-1-inch-Spencer

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack

Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 50 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 100 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-45.65, 132.98399) ft
Left-Zone Right Coordinate: (-9.53096, 141.56025) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (4.57018, 164.82807) ft
Right-Zone Right Coordinate: (41.9377, 176.1772) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft
Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.21

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (34.67929, 146.70771) ft
Length: 35.902643 ft
Direction: 165 °
F of S Dependent: No
Pullout Resistance: 7,900 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 2,900 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 12,409.291 lbs/ft
Max. Pullout Force: 2,900 lbs
Shear Force Applied: 0 lbs
Factored Tensile Capacity: 2,900 lbs

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Length: 37 ft
Direction: 90 °
Shear Force: 2,500 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	49,400	0
Point Load 2	(0, 162)	47,000	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146

Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft^2)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Fig 2.8 Through-Berm-Pseudo-Static-1-inch-Spencer-Other-Combi

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 710
Date: 11/3/2021
Time: 11:59:00 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\
Last Solved Date: 11/3/2021
Last Solved Time: 11:59:07 AM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.8 Through-Berm-Pseudo-Static-1-inch-Spencer-Other-Combi

Kind: SLOPE/W
Method: Spencer
Settings
PWP Conditions Source: Piezometric Line
Apply Phreatic Correction: No
Use Staged Rapid Drawdown: No
Slip Surface
Direction of movement: Right to Left
Use Passive Mode: No
Slip Surface Option: Entry and Exit

Critical slip surfaces saved: 1
Resisting Side Maximum Convex Angle: 1 °
Driving Side Maximum Convex Angle: 5 °
Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 50 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 100 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-45.65, 132.98399) ft
Left-Zone Right Coordinate: (-9.53096, 141.56025) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (4.57018, 164.82807) ft
Right-Zone Right Coordinate: (41.9377, 176.1772) ft
Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft
Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.21

Reinforcements

Reinforcement 1

Type: Anchor
Outside Point: (0, 156) ft
Inside Point: (34.67929, 146.70771) ft
Slip Surface Intersection: (12.247421, 152.71831) ft
Length: 35.902643 ft
Direction: 165 °
F of S Dependent: No
Pullout Resistance: 7,900 psf
Resistance Reduction Factor: 1
Bond Length: 15 ft
Bond Diameter: 0.5 ft
Anchor Spacing: 1 ft
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 3,000 lbs
Reduction Factor: 1
Shear Force: 0 lbs
Shear Reduction Factor: 1

Shear Option: Parallel to Slip
Factored Pullout Resistance: 12,409.291 lbs/ft
Max. Pullout Force: 3,000 lbs
Factored Tensile Capacity: 3,000 lbs
Pullout Force: 3,000 lbs
Pullout Force per Length: 12,409.291 lbs/ft
Available Length: 15 ft
Required Length: 0.24175434 ft
Governing Component: Tensile Capacity

Reinforcement 2

Type: Pile
Outside Point: (0, 163) ft
Inside Point: (0, 126) ft
Slip Surface Intersection: (0, 142.44315) ft
Length: 37 ft
Direction: 90 °
Shear Force: 2,400 lbs
Shear Reduction Factor: 1
Pile Spacing: 1 ft
Shear Option: Perp. to Reinf.
Shear Force Applied: 2,400 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	49,400	0
Point Load 2	(0, 162)	47,000	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133

Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft^2)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Current Slip Surface

Slip Surface: 2,423

F of S: 1.1

Volume: 388.88105 ft^3

Weight: 51,095.847 lbs

Resisting Moment: 1,665,331.8 lbs-ft

Activating Moment: 1,583,373.8 lbs-ft

Resisting Force: 30,824.82 lbs

Activating Force: 29,301.178 lbs

F of S Rank (Analysis): 1 of 4,096 slip surfaces

F of S Rank (Query): 1 of 4,096 slip surfaces

Exit: (-20, 133.01202) ft

Entry: (23.70419, 168.24695) ft

Radius: 74.346362 ft

Center: (-12.35, 186.4) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-19.5	133.16582	-1,882.3472	1,729.522	1,557.2686	50
Slice 2	-18.5	133.48117	-1,902.0247	1,312.6712	1,181.9345	50

Slice 3	-17.277778	133.88997	-1,927.5341	1,021.1027	919.40497	50
Slice 4	-15.833333	134.40123	-1,959.4369	933.92373	840.9087	50
Slice 5	-14.388889	134.94638	-1,993.4542	855.62308	770.40648	50
Slice 6	-12.944444	135.52622	-2,029.6364	785.17675	706.97632	50
Slice 7	-11.5	136.14165	-2,068.0388	721.36941	649.52394	50
Slice 8	-10.055556	136.79363	-2,108.7223	663.02232	596.98798	50
Slice 9	-8.6111111	137.48323	-2,151.7538	609.09739	548.43375	50
Slice 10	-7.1666667	138.21165	-2,197.2069	558.73092	503.08358	50
Slice 11	-5.7222222	138.98017	-2,245.1628	511.2304	460.31392	50
Slice 12	-4.1666667	139.85611	-2,299.8213	437.74603	394.1483	50
Slice 13	-2.5	140.84852	-2,361.7477	345.14251	310.76772	50
Slice 14	-0.83333333	141.9013	-2,427.4411	261.89636	235.81254	50
Slice 15	0.83333333	143.01757	-2,497.0964	1,614.1208	1,453.3609	50
Slice 16	2.5	144.20088	-2,570.9347	1,451.8377	1,307.2406	50
Slice 17	4.1666667	145.45528	-2,649.2092	1,303.2184	1,173.4231	50
Slice 18	5.65	146.63131	-2,722.5939	1,245.2192	1,121.2004	50
Slice 19	6.95	147.71751	-2,790.3726	1,129.9443	1,017.4064	50
Slice 20	8.25	148.85554	-2,861.3858	1,021.6665	919.91268	50
Slice 21	9.55	150.04868	-2,935.8376	919.69255	828.09489	50
Slice 22	10.9	151.3513	-3,017.1211	805.86978	725.60841	50
Slice 23	12.3	152.77315	-3,105.8443	716.22233	644.88948	50
Slice 24	13.7	154.27472	-3,199.5428	430.58359	387.6992	50
Slice 25	15.1	155.86348	-3,298.681	363.28128	327.09994	50
Slice 26	16.5	157.54834	-3,403.8162	299.33559	269.52298	50
Slice 27	17.9	159.34016	-3,515.626	238.61375	214.84879	50
Slice 28	19.3	161.25239	-3,634.9488	181.04453	163.01323	50
Slice 29	20.617365	163.17247	-3,754.7619	125.43969	112.9464	50
Slice 30	21.852095	165.10192	-3,875.16	72.107374	64.925771	50
Slice 31	23.086825	167.17316	-4,004.4052	22.770039	20.502235	50

Fig 2.9a Through-Berm-Static-Spencer-Cantilever

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 709
Date: 11/3/2021
Time: 6:55:54 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.9a Through-Berm-Static-Spencer-Cantilever

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack

Tension Crack Option: (none)

F of S Distribution

F of S Calculation Option: Constant

Advanced

Number of Slices: 30

F of S Tolerance: 0.001

Minimum Slip Surface Depth: 0.1 ft

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb

Unit Weight: 115 pcf

Cohesion': 0 psf

Phi': 34 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

3D

Model: Mohr-Coulomb

Unit Weight: 140 pcf

Cohesion': 0 psf

Phi': 42 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range

Left-Zone Left Coordinate: (-45.65, 132.98399) ft

Left-Zone Right Coordinate: (-9.53096, 141.56025) ft

Left-Zone Increment: 15

Right Projection: Range

Right-Zone Left Coordinate: (4.57018, 164.82807) ft

Right-Zone Right Coordinate: (41.9377, 176.1772) ft

Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0

Reinforcements

Reinforcement 1

Type: Pile

Outside Point: (0, 163) ft

Inside Point: (0, 126) ft

Length: 37 ft

Direction: 90 °

Shear Force: 4,000 lbs

Shear Reduction Factor: 1

Pile Spacing: 1 ft

Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	9,000	0
Point Load 2	(0, 162)	8,500	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8

Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D	19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Fig 2.9b Through-Berm-Pseudo-Static-1-inch-Spencer-Cantilever

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Gould, Nicole
Revision Number: 709
Date: 11/3/2021
Time: 6:55:54 AM
Tool Version: 8.16.5.15361
File Name: 09.05R 2+60-Rev-ClassC-Bending-Rev-Oct-26.gsz
Directory: c:\users\nicole.gould\documents\projectwise\workingdir\wsdot\dms19127\

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Fig 2.9b Through-Berm-Pseudo-Static-1-inch-Spencer-Cantilever

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °

Driving Side Maximum Convex Angle: 5 °
Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 140 pcf
Cohesion': 50 psf
Phi': 42 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb
Unit Weight: 115 pcf
Cohesion': 100 psf
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-45.65, 132.98399) ft
Left-Zone Right Coordinate: (-9.53096, 141.56025) ft
Left-Zone Increment: 15
Right Projection: Range
Right-Zone Left Coordinate: (11.4, 166.28) ft
Right-Zone Right Coordinate: (55.9, 176.95484) ft
Right-Zone Increment: 15
Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.21

Reinforcements

Reinforcement 1

Type: Pile

Outside Point: (0, 163) ft

Inside Point: (0, 126) ft

Length: 37 ft

Direction: 90 °

Shear Force: 5,100 lbs

Shear Reduction Factor: 1

Pile Spacing: 1 ft

Shear Option: Perp. to Reinf.

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 163)	49,400	0
Point Load 2	(0, 162)	47,000	180

Points

	X (ft)	Y (ft)

Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163
Point 30	-55	133

Regions

	Material	Points	Area (ft^2)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

See Fei.E-2.10b

GLE-Static-Ka

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Dimitriu, Dan
Revision Number: 538
Date: 03/05/2021
Time: 4:50:07 PM
Tool Version: 8.16.1.13452
File Name: 09.05R 2+60-Rev-ClassC-Bending-09-June.gsz
Directory: C:\Users\dan.dimitriu\Documents\I-405-PS19203160\Segment-2A\Soldier-Pile-09.05R-A-R1\WSDOT-Comments\Global\
Last Solved Date: 03/05/2021
Last Solved Time: 4:50:10 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

GLE-Static-Ka

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack

See Fei.E-2.10b

Tension Crack Option: (none)

F of S Distribution

F of S Calculation Option: Constant

Advanced

Number of Slices: 30

F of S Tolerance: 0.001

Minimum Slip Surface Depth: 0.1 ft

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb

Unit Weight: 115 pcf

Cohesion': 0 psf

Phi': 34 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

3D

Model: Mohr-Coulomb

Unit Weight: 140 pcf

Cohesion': 0 psf

Phi': 42 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Point

Left Coordinate: (0, 145) ft

Left-Zone Increment: 15

Right Projection: Range

Right-Zone Left Coordinate: (4.06274, 164.6251) ft

Right-Zone Right Coordinate: (39.45, 175.225) ft

Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

See Fei.E-2.10b

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 155)	5,300	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163

Point 30	-55	133

See Fei.E-2.10b

Regions

	Material	Points	Area (ft^2)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D	19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Current Slip Surface

Slip Surface: 37
F of S: 1.0
Volume: 95.318863 ft^3
Weight: 11,628.606 lbs
Resisting Moment: 242,526.33 lbs-ft
Activating Moment: 243,727.54 lbs-ft
Resisting Force: 3,557.8147 lbs
Activating Force: 3,575.6898 lbs
F of S Rank (Analysis): 1 of 256 slip surfaces
F of S Rank (Query): 1 of 256 slip surfaces
Exit: (0, 145) ft
Entry: (9.1857611, 165.83715) ft
Radius: 93.545718 ft
Center: (-12.35, 186.4) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	0.15625	145.26428	-2,637.2911	585.3786	527.07726	0
Slice 2	0.46875	145.79687	-2,670.5247	578.45418	520.84248	0
Slice 3	0.78125	146.33765	-2,704.2696	574.64067	517.40879	0
Slice 4	1.09375	146.88692	-2,738.5439	573.52387	516.40321	0
Slice 5	1.40625	147.44498	-2,773.3668	574.62011	517.39027	0
Slice 6	1.71875	148.01216	-2,808.7588	577.37053	519.86676	0
Slice 7	2.03125	148.58881	-2,844.7417	581.13871	523.25964	0
Slice 8	2.34375	149.1753	-2,881.3389	585.21352	526.92862	0
Slice 9	2.65625	149.77205	-2,918.5756	588.81876	530.17479	0
Slice 10	2.96875	150.37947	-2,956.4787	591.13126	532.25698	0
Slice 11	3.28125	150.99803	-2,995.0772	591.30832	532.4164	0

See Fei.E-2.10b

Slice 12	3.59375	151.62824	-3,034.4024	588.52464	529.90997	0
Slice 13	3.90625	152.27064	-3,074.4881	582.01729	524.05072	0
Slice 14	4.21875	152.92582	-3,115.3712	571.13571	514.25291	0
Slice 15	4.53125	153.59441	-3,157.0914	555.39218	500.07736	0
Slice 16	4.84375	154.27712	-3,199.6923	534.50661	481.27191	0
Slice 17	5.1413338	154.9407	-3,241.0999	508.53002	457.88249	0
Slice 18	5.4240014	155.58449	-3,281.2724	478.28978	430.65405	0
Slice 19	5.7161863	156.2644	-3,323.6987	591.79762	399.17253	0
Slice 20	6.0178885	156.98222	-3,368.4907	541.1301	364.99686	0
Slice 21	6.3195906	157.71729	-3,414.359	485.47927	327.45991	0
Slice 22	6.6212928	158.47072	-3,461.3728	426.68766	287.80446	0
Slice 23	6.9229949	159.24373	-3,509.609	366.60365	247.27728	0
Slice 24	7.2246971	160.03773	-3,559.1542	306.93687	207.03153	0
Slice 25	7.5263992	160.85426	-3,610.1058	249.14847	168.05277	0
Slice 26	7.8281014	161.6951	-3,662.5745	194.38485	131.11423	0
Slice 27	8.1298036	162.56229	-3,716.6868	143.45479	96.761479	0
Slice 28	8.4315057	163.45814	-3,772.5882	96.843237	65.321588	0
Slice 29	8.7332079	164.38538	-3,830.4479	54.751064	36.930059	0
Slice 30	9.03491	165.34718	-3,890.4642	17.149963	11.567796	0

See Fig.E-2.10c

GLE-Seismic-Kae-0.1inch

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Dimitriu, Dan
Revision Number: 652
Date: 09/06/2021
Time: 1:51:23 PM
Tool Version: 8.16.1.13452
File Name: 09.05R 2+60-Rev-ClassC-Bending-09-June.gsz
Directory: C:\Users\dan.dimitriu\Documents\I-405-PS19203160\Segment-2A\Soldier-Pile-09.05R-A-R1\WSDOT-Comments\Global\
Last Solved Date: 09/06/2021
Last Solved Time: 2:19:10 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

GLE-Seismic-Kae-0.1inch

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack

See Fig.E-2.10c

Tension Crack Option: (none)

F of S Distribution

F of S Calculation Option: Constant

Advanced

Number of Slices: 30

F of S Tolerance: 0.001

Minimum Slip Surface Depth: 0.1 ft

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb

Unit Weight: 140 pcf

Cohesion': 50 psf

Phi': 42 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb

Unit Weight: 115 pcf

Cohesion': 100 psf

Phi': 34 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Point

Left Coordinate: (0, 145) ft

Left-Zone Increment: 15

Right Projection: Range

Right-Zone Left Coordinate: (4.06274, 164.6251) ft

Right-Zone Right Coordinate: (39.45, 175.225) ft

Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

See Fig.E-2.10c

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.366

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 155)	10,200	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163

Point 30	-55	133

See Fig.E-2.10c

Regions

	Material	Points	Area (ft²)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2	3D -Apparent-Cohesion	19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Current Slip Surface

Slip Surface: 129
F of S: 1.0
Volume: 247.78812 ft³
Weight: 31,342.837 lbs
Resisting Moment: 855,742.09 lbs-ft
Activating Moment: 860,734.25 lbs-ft
Resisting Force: 16,173.838 lbs
Activating Force: 16,269.552 lbs
F of S Rank (Analysis): 1 of 256 slip surfaces
F of S Rank (Query): 1 of 256 slip surfaces
Exit: (0, 145) ft
Entry: (24.795294, 168.31969) ft
Radius: 393.88359 ft
Center: (-12.35, 186.4) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	0.41666667	145.36025	-2,643.2799	1,923.6976	1,732.1051	50
Slice 2	1.25	146.08281	-2,688.3672	1,799.4576	1,620.2389	50
Slice 3	2.0833333	146.80946	-2,733.7105	1,671.6426	1,505.1537	50
Slice 4	2.9166667	147.54025	-2,779.3118	1,542.4388	1,388.8181	50
Slice 5	3.75	148.27521	-2,825.1728	1,413.9722	1,273.1463	50
Slice 6	4.5833333	149.01435	-2,871.2957	1,288.2473	1,159.9431	50
Slice 7	5.4333333	149.77268	-2,918.6154	1,160.5682	1,044.9803	50
Slice 8	6.3	150.5504	-2,967.145	1,033.5978	930.65568	50
Slice 9	7.1666667	151.33276	-3,015.9643	915.65236	824.45709	50
Slice 10	8.0333333	152.1198	-3,065.0758	807.64863	727.21009	50
Slice 11	8.9	152.91157	-3,114.4817	710.12669	639.40094	50

See Fig.E-2.10c

Slice 12	9.7666667	153.70809	-3,164.1846	623.26066	561.18642	50
Slice 13	10.608333	154.48615	-3,212.736	551.4716	496.54726	50
Slice 14	11.425	155.24553	-3,260.1214	493.43712	444.29278	50
Slice 15	12.241667	156.00925	-3,307.7769	443.67701	399.48857	50
Slice 16	13.058333	156.77732	-3,355.7047	401.59284	361.59582	50
Slice 17	13.875	157.54979	-3,403.9069	366.43927	329.9434	50
Slice 18	14.691667	158.3267	-3,452.3858	337.35437	303.75524	50
Slice 19	15.508333	159.10807	-3,501.1436	313.38889	282.17662	50
Slice 20	16.325	159.89395	-3,550.1828	293.53373	264.29896	50
Slice 21	17.141667	160.68438	-3,599.5055	276.74513	249.18243	50
Slice 22	17.958333	161.47939	-3,649.1142	261.96726	235.87638	50
Slice 23	18.775	162.27903	-3,699.0113	248.15256	223.43757	50
Slice 24	19.591667	163.08332	-3,749.1994	234.27967	210.94636	50
Slice 25	20.399608	163.88363	-3,799.1383	212.67861	191.49668	50
Slice 26	21.198824	164.67988	-3,848.8244	181.36412	163.30098	50
Slice 27	21.998039	165.48071	-3,898.7964	145.51915	131.02603	50
Slice 28	22.797255	166.28617	-3,949.0567	104.25761	93.873978	50
Slice 29	23.596471	167.09628	-3,999.6079	56.836061	51.175419	50
Slice 30	24.395686	167.9111	-4,050.4525	2.6712049	2.4051637	50

GLE-Static-Ka-Forward-Comp

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Dimitriu, Dan
Revision Number: 557
Date: 04/05/2021
Time: 8:43:07 AM
Tool Version: 8.16.1.13452
File Name: 09.05R 2+60-Rev-ClassC-Bending-09-June.gsz
Directory: C:\Users\dan.dimitriu\Documents\I-405-PS19203160\Segment-2A\Soldier-Pile-09.05R-A-R1\WSDOT-Comments\Global\
Last Solved Date: 04/05/2021
Last Solved Time: 8:43:10 AM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

GLE-Static-Ka-Forward-Comp

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack

See Fig.E-2.11b

Tension Crack Option: (none)

F of S Distribution

F of S Calculation Option: Constant

Advanced

Number of Slices: 30

F of S Tolerance: 0.001

Minimum Slip Surface Depth: 0.1 ft

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

3B

Model: Mohr-Coulomb

Unit Weight: 115 pcf

Cohesion': 0 psf

Phi': 34 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

3D

Model: Mohr-Coulomb

Unit Weight: 140 pcf

Cohesion': 0 psf

Phi': 42 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Point

Left Coordinate: (0, 133) ft

Left-Zone Increment: 15

Right Projection: Range

Right-Zone Left Coordinate: (4.06274, 164.6251) ft

Right-Zone Right Coordinate: (39.45, 175.225) ft

Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

See Fig.E-2.11b

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 155)	16,300	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163

See Fig.E-2.11b

Point 30	-55	133

Regions

	Material	Points	Area (ft²)
Region 1	3D	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2		19,18,17,16,15,14,23	164.5
Region 3	3B	26,13,22,20,21	133.9
Region 4	3D	14,15,24,25	39.5
Region 5	3D	1,15,24,25,12,2	4,983.5

Current Slip Surface

Slip Surface: 78
F of S: 1.0
Volume: 296.27566 ft³
Weight: 38,518.122 lbs
Resisting Moment: 1,036,701.7 lbs-ft
Activating Moment: 1,022,365.2 lbs-ft
Resisting Force: 12,136.839 lbs
Activating Force: 11,977.021 lbs
F of S Rank (Analysis): 1 of 256 slip surfaces
F of S Rank (Query): 1 of 256 slip surfaces
Exit: (0, 133) ft
Entry: (14.361378, 166.87228) ft
Radius: 56.077305 ft
Center: (-12.35, 186.4) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	0.25	133.28018	-1,889.483	69.325064	62.420568	0
Slice 2	0.75	133.84826	-1,924.9313	67.109051	60.425261	0
Slice 3	1.25	134.43217	-1,961.3674	87.07185	78.399846	0
Slice 4	1.75	135.03269	-1,998.8399	129.49118	116.59438	0
Slice 5	2.25	135.65068	-2,037.4023	194.75793	175.36083	0
Slice 6	2.75	136.28707	-2,077.1135	283.26675	255.05452	0
Slice 7	3.25	136.94293	-2,118.0387	395.2492	355.88398	0
Slice 8	3.75	137.6194	-2,160.2503	530.53434	477.69526	0
Slice 9	4.25	138.31778	-2,203.8293	688.22257	619.67839	0
Slice 10	4.75	139.03953	-2,248.8666	866.26648	779.98985	0
Slice 11	5.2363636	139.76522	-2,294.1499	1,052.2987	947.49403	0

See Fig.E-2.11b

Slice 12	5.7090909	140.4952	-2,339.7002	1,239.7488	1,116.2749	0
Slice 13	6.1818182	141.25093	-2,386.8582	1,429.7283	1,287.3332	0
Slice 14	6.6545455	142.03448	-2,435.7515	1,613.0028	1,452.3543	0
Slice 15	7.1272727	142.8482	-2,486.5275	1,778.2319	1,601.1272	0
Slice 16	7.6	143.69482	-2,539.357	1,912.5967	1,722.1098	0
Slice 17	8.0727273	144.57758	-2,594.441	2,003.0417	1,803.5468	0
Slice 18	8.5454545	145.50028	-2,652.0177	2,038.1111	1,835.1235	0
Slice 19	9.0181818	146.46753	-2,712.3738	2,010.1208	1,809.9209	0
Slice 20	9.4909091	147.48492	-2,775.8592	1,917.1423	1,726.2027	0
Slice 21	9.9636364	148.55944	-2,842.9088	1,764.1284	1,588.4283	0
Slice 22	10.449907	149.73481	-2,916.2522	1,558.3727	1,403.1651	0
Slice 23	10.949722	151.02805	-2,996.9505	1,314.0641	1,183.1886	0
Slice 24	11.449537	152.42724	-3,084.2597	1,054.9184	949.85284	0
Slice 25	11.949352	153.95941	-3,179.8672	800.90899	721.14169	0
Slice 26	12.449167	155.66621	-3,286.3716	567.52597	511.00267	0
Slice 27	12.948982	157.61841	-3,408.189	364.47069	328.17088	0
Slice 28	13.448797	159.95789	-3,554.1726	195.99802	176.47741	0
Slice 29	14.030041	164.06044	-3,810.1717	58.105397	39.192585	0

See Fig.E-2.11c

GLE-Seismic-Kae--Forward-Comp-0.1inches

File Information

File Version: 8.16
Title: 09.05R 2+70
Created By: Nunes, Miguel
Last Edited By: Dimitriu, Dan
Revision Number: 652
Date: 09/06/2021
Time: 1:51:23 PM
Tool Version: 8.16.1.13452
File Name: 09.05R 2+60-Rev-ClassC-Bending-09-June.gsz
Directory: C:\Users\dan.dimitriu\Documents\I-405-PS19203160\Segment-2A\Soldier-Pile-09.05R-A-R1\WSDOT-Comments\Global\
Last Solved Date: 09/06/2021
Last Solved Time: 1:51:52 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

GLE-Seismic-Kae--Forward-Comp-0.1inches

- Kind: SLOPE/W
- Method: Morgenstern-Price
- Settings
  - Side Function
    - Interslice force function option: Half-Sine
  - PWP Conditions Source: Piezometric Line
  - Apply Phreatic Correction: No
  - Use Staged Rapid Drawdown: No
- Slip Surface
  - Direction of movement: Right to Left
  - Use Passive Mode: No
  - Slip Surface Option: Entry and Exit
  - Critical slip surfaces saved: 1
  - Resisting Side Maximum Convex Angle: 1 °
  - Driving Side Maximum Convex Angle: 5 °
  - Optimize Critical Slip Surface Location: No
  - Tension Crack

Tension Crack Option: (none)

See Fig.E-2.11c

F of S Distribution

F of S Calculation Option: Constant

Advanced

Number of Slices: 30

F of S Tolerance: 0.001

Minimum Slip Surface Depth: 0.1 ft

Search Method: Root Finder

Tolerable difference between starting and converged F of S: 3

Maximum iterations to calculate converged lambda: 20

Max Absolute Lambda: 2

Materials

3D -Apparent-Cohesion

Model: Mohr-Coulomb

Unit Weight: 140 pcf

Cohesion': 50 psf

Phi': 42 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

3B-Apparent-Cohesion

Model: Mohr-Coulomb

Unit Weight: 115 pcf

Cohesion': 100 psf

Phi': 34 °

Phi-B: 0 °

Pore Water Pressure

Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Point

Left Coordinate: (0, 133) ft

Left-Zone Increment: 15

Right Projection: Range

Right-Zone Left Coordinate: (4.06274, 164.6251) ft

Right-Zone Right Coordinate: (39.45, 175.225) ft

Right-Zone Increment: 15

Radius Increments: 15

Slip Surface Axis

Coordinate: (-12.35, 186.4) ft

Slip Surface Limits

Left Coordinate: (-100.1, 132.95) ft

Right Coordinate: (100.05, 180) ft

See Fig.E-2.11c

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-100	103
Coordinate 2	100	103

Seismic Coefficients

Horz Seismic Coef.: 0.3

Point Loads

	Coordinate (ft)	Magnitude (lbs)	Direction (°)
Point Load 1	(0, 155)	27,000	180

Points

	X (ft)	Y (ft)
Point 1	-100.1	132.95
Point 2	-100.1	82.8
Point 3	100.05	82.8
Point 4	100.05	180
Point 5	76.5	178
Point 6	70.25	176.8
Point 7	61.3	176.8
Point 8	47.35	177.2
Point 9	41	176
Point 10	36.6	173.8
Point 11	35	169
Point 12	0	82.8
Point 13	0	163
Point 14	0	133
Point 15	-20	133
Point 16	-20	138
Point 17	-19	138
Point 18	-18	137
Point 19	-5	144
Point 20	10.2	157.5
Point 21	20	168
Point 22	0	154
Point 23	0	145
Point 24	-19.5	131
Point 25	0	131
Point 26	5	165
Point 27	-35	146
Point 28	-30	148
Point 29	-12	163

Point 30	-55	133

See Fig.E-2.11c

Regions

	Material	Points	Area (ft²)
Region 1	3D -Apparent-Cohesion	3,4,5,6,7,8,9,10,11,21,20,22,23,14,25,12	8,967.9
Region 2		19,18,17,16,15,14,23	164.5
Region 3	3B-Apparent-Cohesion	26,13,22,20,21	133.9
Region 4	3D -Apparent-Cohesion	14,15,24,25	39.5
Region 5	3D -Apparent-Cohesion	1,15,24,25,12,2	4,983.5

Current Slip Surface

Slip Surface: 80
F of S: 1.0
Volume: 307.47889 ft³
Weight: 40,070.077 lbs
Resisting Moment: 1,100,572 lbs-ft
Activating Moment: 1,094,756.6 lbs-ft
Resisting Force: 12,702.689 lbs
Activating Force: 12,634.401 lbs
F of S Rank (Analysis): 1 of 256 slip surfaces
F of S Rank (Query): 1 of 256 slip surfaces
Exit: (0, 133) ft
Entry: (14.361378, 166.87228) ft
Radius: 49.414158 ft
Center: (-12.35, 186.4) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	0.25	133.25513	-1,887.9202	-1,126.8125	-1,014.5866	50
Slice 2	0.75	133.77294	-1,920.2317	-984.40529	-886.36251	50
Slice 3	1.25	134.30621	-1,953.5073	-815.85248	-734.59688	50
Slice 4	1.75	134.85567	-1,987.7941	-622.71534	-560.69541	50
Slice 5	2.25	135.42217	-2,023.1433	-406.3338	-365.86459	50
Slice 6	2.75	136.0066	-2,059.6118	-168.0244	-151.28985	50
Slice 7	3.25	136.60998	-2,097.2625	90.670876	81.640424	50
Slice 8	3.75	137.23342	-2,136.1653	367.67544	331.05645	50
Slice 9	4.25	137.87818	-2,176.3986	660.00321	594.26956	50
Slice 10	4.75	138.54568	-2,218.0502	963.32294	867.37987	50
Slice 11	5.2363636	139.21794	-2,259.9996	1,259.1382	1,133.7332	50

See Fig.E-2.11c

Slice 12	5.7090909	139.89531	-2,302.2671	1,539.3368	1,386.025	50
Slice 13	6.1818182	140.59772	-2,346.0979	1,807.103	1,627.1229	50
Slice 14	6.6545455	141.32719	-2,391.6164	2,051.4375	1,847.1226	50
Slice 15	7.1272727	142.086	-2,438.9663	2,259.6302	2,034.5802	50
Slice 16	7.6	142.87684	-2,488.315	2,418.0533	2,177.2249	50
Slice 17	8.0727273	143.70288	-2,539.8595	2,513.5241	2,263.1873	50
Slice 18	8.5454545	144.56785	-2,593.8341	2,535.205	2,282.7088	50
Slice 19	9.0181818	145.47631	-2,650.5219	2,476.7874	2,230.1094	50
Slice 20	9.4909091	146.43381	-2,710.2695	2,338.4754	2,105.5727	50
Slice 21	9.9636364	147.44727	-2,773.5099	2,128.1274	1,916.1745	50
Slice 22	10.435456	148.52336	-2,840.6579	1,864.1843	1,678.519	50
Slice 23	10.906368	149.67336	-2,912.4175	1,566.6119	1,410.5837	50
Slice 24	11.377281	150.9148	-2,989.8832	1,254.6686	1,129.7087	50
Slice 25	11.848193	152.26981	-3,074.4359	950.03605	855.4163	50
Slice 26	12.319105	153.77175	-3,168.1572	670.3919	603.62357	50
Slice 27	12.790018	155.47552	-3,274.4724	427.63526	385.04452	50
Slice 28	13.26093	157.48504	-3,399.8662	227.51116	204.85197	50
Slice 29	13.731843	160.05997	-3,560.5423	70.159946	63.172299	50
Slice 30	14.164338	164.20433	-3,819.1504	-117.12241	-79.000062	100